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IGNEOUS ROCKS AND IRON ORES OF KIIRUNAVAARA, LUOSSAVAARA AND TUOLLUVAARA.

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The Luossavaara-Kiirunavaara company, owner of the great iron ore fields of Kiirunavaara and Gellivare in Swedish Lapland, has in the last years, on the initiative of its director, Dr. Hj. Lundbohm, arranged a series of scientific and practical researches. Those dealing with the geology of the ore-bearing rocks are, of course, among the most extensive. A general survey of the geology of the Kiruna district, by Hj. Lundbohm,[1] and the monograph cited above are among the papers hitherto published. As some knowledge of the geology of the surrounding areas is required for the understanding of the author's work, a very short review of these phenomena, especially of the sketch just mentioned, will first be given here.

The bed-rock in the ore-bearing part of northern Lapland is practically unanimously regarded to be of Precambrian age. It is composed of superficial and deep-seated rocks, the former being predominant. Most common are syenite-porphyries and quartz-bearing porphyries, further on, greenstones showing a close relationship to the syenite-porphyries. These superficial rocks have partly assumed an eugranitic, grained structure, evidently

[1] "Sketch of the Geology of the Kiruna District," *Geol. Fören. Stockholm Förh.*, Vol. 32, 1910, p. 751; also in the guides for the Eleventh International Geological Congress, Stockholm, 1910.

due to slower cooling in deeper parts of the outflows. Tuff rocks are rather common. True sedimentary series also occur: graywackes, conglomerates and sandstones, sometimes alternating with the effusive rocks. The intrusive rocks are granite, syenite, diorite, gabbro, diabase and porphyritic dike rocks. The iron ores are always associated with rocks of a more or less pronounced effusive character, generally syenite-porphyries and quartz-porphyries of moderate acidity. Because of the continuous morainic covering, and the great swamps and bogs, exposures are generally scant, it consequently being very difficult to make out the structure of the region. In this respect, the Kiruna district is most probably the best part, and also with regard to the degree of metamorphism. Although the rocks in the region are strongly folded—they generally stand nearly vertical—and doubtless in part also have been subjected to contact metamorphism, they have within large areas still kept their original structure nearly intact. This is the case within the main part of the Kiruna district. This district might conveniently be divided into two subdivisions, of which the most important (western) one comprises the iron ore mountains Kiirunavaara and Luossavaara and their continuation northwards. The direction of strike is, in the southern parts nearly north-south, but more to the north it turns to west-southwest—east-northeast. The dip is generally rather steep to the east or southeast. The examinations have clearly shown that when going from west to east we pass continuously from older to younger members of the series, the sequence being:

(Basement as yet unknown.)

1. Effusive beds of a peculiar greenstone type (for the present called soda greenstone), sometimes with interstratified tuff bands.
2. The Kurravaara conglomerate, a zone of conglomerate probably to a great extent of tuffogeneous origin.
3. Syenite-porphyries, on Kiirunavaara in the lower part crystallized as syenite.
4. On Kiirunavaara and Luossavaara, magnetite ores.

5. Quartz-porphyry, with an agglomeratic zone.
6. On Luossavaara, a rather narrow band of magnetite.[1]
7. On Luossavaara, northward and a short distance southward, a series of quartzitic and sericitic rocks (the former are silicified tuffs), partly hematite-bearing, with some interstratified effusive beds of syenite-porphyry and subordinately of quartz-porphyry.
8. Phyllite and graywacke, with conglomerates. Among the pebbles are quartz-porphyry phases belonging to no. 5, and iron ores.
9. Quartzitic sandstone, with conglomerate bands.

For the sake of simplicity, nos. 1 and 2 are grouped together as the Kurravaara complex, and nos. 7 to 9 as the Hauki complex. It must be emphasized that this grouping is used chiefly in order to obtain convenient terms for these two groups of

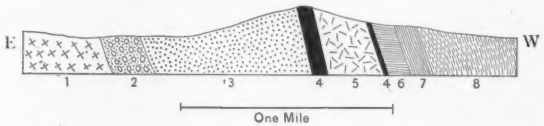

FIG. 64. Section through Luossavaara W-E. Scale 1:50,000. 1, Soda greenstone; 2, Kurravaara conglomerate; 3, syenite-porphyry; 4, magnetite ore; 5, quartzites, etc.; 6, phyllite and graywacke; 7, sandstone.

rocks surrounding the ore-bearing prophyries, and that it does not at all mean any real unconformity between the two "complexes."[2] The structure of the district is on the whole rather regular, although the contact of the quartz-porphyry with the Hauki complex in some places is determined by dislocations.

The eastern district consists mainly of a quartz-prophyry chemically similar to no. 5 in the sequence mentioned in the text above, but with a different structure, further of a more acid quartz-porphyry, of syenite-porphyries and of variable greenstones. The structure of the district is very difficult to explain,

[1] It is not proved that this little exposed ore body is older than no. 7.

[2] The stratigraphy of the district will be discussed in papers in preparation by other authors.

as the morainic and boggy covering here generally is more continuous than in the western district, but it seems that the rocks form nearly horizontal beds. From the same cause the boundary between the two districts is also unknown, but it must mark some dislocation, perhaps an overthrust.

The monograph by the present writer describes the syenite-porphyries, quartz-porphyries and magnetite ores of the western district and the bottom parts of the Hauki complex, as well as the northern part of the eastern district. The work mainly consists of petrographic descriptions, giving the macroscopic and microscopic characters of the rocks, and of chemical calculations based upon nineteen rock analyses (four of which were published in 1898 by Lundbohm and Bäckström[1]), made at the laboratory of the Geological Survey of Sweden. Special attention is given to facts having a great importance for the problem of the origin of the ores. As the author's results in some rather significant points differ from those obtained by previous students of the geology of the field in question, he has been obliged to treat some parts of the subject in considerable detail, but he has tried to arrange the work so as to let a reader wishing to get only the chief contents of it find them easily. The theoretical statements are therefore brought together in the final chapters. The work comprises 278 pages and contains 68 illustrations, most of which are photographs of rock outcrops, hand specimens and thin sections. Together with it is published a geological map of Kiirunavaara and Luossavaara, scale 1 : 8000, based on examinations chiefly made by Hj. Lundbohm, N. Zeuzén, N. Sundius, R. Looström and the author.

We first turn to the syenite rocks of the western district, the foot wall rocks of the main iron ores. These rocks are rather well exposed on the two ore mountains and can be followed to a point about seven kilometers northeast of the summit of Luossavaara. The exposures are chiefly found on the mountains. Both on Kiirunavaara and Luossavaara and some kilometers further to the northeast, the syenite rocks have been found to

[1] *Geol. Fören. Stockholm Förh.*, Vol. 20, 1898, p. 68.

form only *one* bed, varying with regard to structure and composition, but with no sharp contacts within it, except in some places on Kiirunavaara, where well-defined dikes of syenite-porphyry cut the older main mass of syenite rocks. This absence of a sharp contact is especially remarkable with regard to the syenite. This relatively fine-grained rock occurs on westernmost Kiirunavaara and passes eastwards very evidently into the porphyries forming the main mass of the mountain west of the ore body. Especially detailed investigations have confirmed the opinion that there is a real transition and that no contact between the rocks has obliterated through any kind of metamorphism. According to the author's opinion, the syenite rocks of Kiiruna-

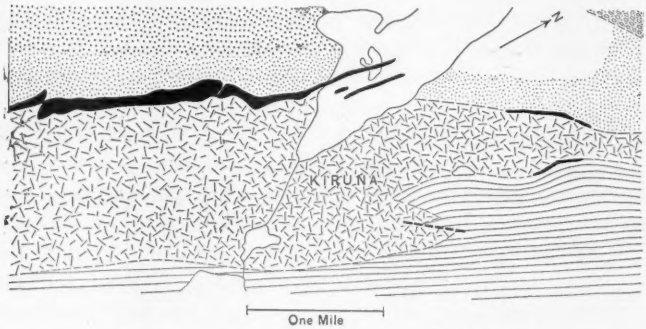

FIG. 65. Geological sketch-map of the surroundings of Kiruna. Kiirunavaara is to the left, Luossavaara to the right. The signs indicate: rings, Kurravaara conglomerate; closely dotted, syenite; dotted, syenite-porphyry; short lines at random, quartz-porphyry; lineated, Hauki complex; black, magnetite ore. Areas where the bed-rock is unknown (mostly lakes) are left white; the heavy broken black lines indicate a fault, else the contact between the quartz-porphyry and the Hauki complex is conformable, though in some places disturbed by folding.

vaara (except the dikes) form one bed, the result of a "Massenerguss" to which most probably also the similar rocks of Luossavaara and those further northeastward belong. The syenite must consequently be regarded as the lower part of the extruded body, which has cooled more slowly, but the thickness of this body has only within a rather narrow area been great enough to produce such a structure.

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The syenite varies considerably as regards aspect and composition. It is as a rule medium- to fine-grained, in the transition forms to the porphyries porphyritic; the color is brown, gray, grayish-purple or yellowish. Feldspar is the chief constituent, an acid albite-oligoclase with high content of perthitic laths of potash feldspar. The dominating dark minerals are a diopsidic augite, and magnetite, further on there is titanite and apatite; biotite, quartz and zircon are more rarely seen. The augite is usually more or less uralitized. The structure of the syenite is always massive and shows many peculiarities. The augite is often intergrown with the feldspar in a very complicated manner. A more important feature is the mode of occurrence of the titanite, which sometimes forms a kind of matrix to the other minerals, filling their interstices, but as a rule occurs as evidently new formed in the feldspar or, even more beautifully, in the apatite. Transitions between these different structural forms occur. The magnetite shows some tendencies of the same character, being often squeezed in between the feldspar. The author explains the appearance of the titanite as follows: The crystallization of the mineral was delayed and it became the last crystallizing primary constituent of the rock—as it seems evident that it really has crystallized from the same magmatic solution as the other constituents—but it was not in equilibrium with the already solidified part of the magma, as it has partly replaced the older constituents.

The syenite-porphyries of Kiirunavaara vary as does the syenite. They are as a rule evidently porphyritic with phenocrysts of feldspar (usually ranging from one up to ten millimeters) and of augite or uralite, in a fine-grained or dense ground mass of a generally gray or grayish red color. A very conspicuous feature is the occurrence of a peculiar nodular structure. The nodules are amygdule-like, generally well-rounded, ellipsoidal or nearly spheroidal, sometimes elongated and fluidally arranged. Most often they are rather sharply defined against the rock con-

taining them and are compact or drusy. The most common mineral in these nodules is a dark-green hornblende, one or a few prisms of which usually form a nodule, but magnetite, titanite and apatite are also common. More rare is feldspar, which when occurring generally coats the walls of the filled cavity. Also biotite and some other minerals have been found. When the nodules occur scattered in the gray porphyry every one of them is surrounded by a light zone some millimeters wide. When, on the other hand, the nodules lie close to one another, these light rings coalesce and the whole compact rock gets the pinkish color of the rings. The microscopic examination of the porphyries shows that the feldspar in their phenocrysts and groundmass has an average composition similar to that of the feldspar in the syenite, but the plagioclase component of the phenocrysts is somewhat more basic and their potash-feldspar content lower than that of the perthite of the syenite, the albite and especially the orthoclase molecules being more abundant in the groundmass. The augite is similar to that of the syenite and generally strongly uralitized. The groundmass consists of feldspar, augite and uralite, magnetite, and more subordinately apatite, biotite, etc. Titanite appears both in the feldspar phenocrysts and in the groundmass and is always evidently newly-formed. The structure of the groundmass, especially in the coarser phases, is rather similar to that of the syenite, but may also be trachytoidal or spherulitic. The nodules show many interesting features. There are often seen hornblendes and especially feldspars which are common to a nodule and the surrounding rock, in such a way that they on one side point out into the nodule, on the other side continue in the groundmass; that is to say, the nodule has, with regard to crystals occurring in this way, the character of a miarolitic cavity. There are also phenomena called by the author "embryonal nodules," indistinctly defined patches in the groundmass with coarser grain and partly another composition than that of the groundmass in general. The light zones around the nodules consist of feldspar groundmass, differing from the normal porphyry groundmass only by the absence of the dark minerals.

The pinkish porphyry rich in nodules shows a similar character; with the exception of the nodules it is a pure feldspar porphyry, but has quite the same structure as the gray porphyry.

Among the porphyries already described there appear locally "schlieren" of a somewhat different composition. Here and there a porphyry occurs, the groundmass of which consists of

FIG. 66. Thin section of syenite-porphyry from Kiirunavaara, local phase rich in magnetite and with nodules of magnetite, hornblende, apatite, titanite and feldspar. Ordinary light, magnified ten times. The white zones surrounding the darker masses of the nodules consist of the zone of feldspar groundmass and, within it, of a ring of greater feldspars belonging to the nodules and causing the uneven outlines of the magnetite lumps.

feldspar and up to twenty per cent. or more of magnetite, but without dark silicates, and carrying nodules of magnetite and other minerals. There are also more rarely seen phases with an apatite content of some ten per cent., which at the same time are rather rich in magnetite. These phases are by transition forms connected with the normal phases already described.

Some of the porphyry dikes on Kiirunavaara consist of syenite-porphyry and a few of quartz-porphyry. The former generally run nearly west-east; some of them are older than the great ore body but some are younger, one cutting right across the ore. The rock is somewhat more acid than the syenitic rocks already described, and further differs from these in a very low content of magnetite. Structurally it is most similar to the quartz-porphyry forming the hanging wall of the ores. The main dike of quartz-porphyry strikes nearly north-south and reaches a length of more than two kilometers, with a width of some ten meters. A smaller dike cuts the ore in the southernmost part of the mountain. The rock is more acid than any other rock of the western district, and carries phenocrysts of feldspar and of quartz; the groundmass is sometimes beautifully granophyric.

The syenite-porphyries on Luossavaara are very similar to the massive types (*i. e.* those which do not form dikes) of Kiirunavaara, especially to the gray type predominating there. They are sometimes rather rich in magnetite. To a great extent they are interwoven with dikes and veins of magnetite, ranging in thickness from some meters down to less than one millimeter. Beside the magnetite, there is much titanite, and some quartz and hornblende. Veins of quartz and specularite are often associated with these dikes.

To the north of Luossavaara there are some outcrops of a grayish porphyry, along the contact with the Kurravaara conglomerate. To the northeast from the same mountain, porphyries are found macroscopically similar to the above described gray and reddish phases, but there also appears in considerable masses the type rich in magnetite which occurs only subordinately on Kiirunavaara and Luossavaara. The normal porphyries consist of an albite feldspar, whose content of anorthite and of intergrown potash-feldspar is very low, and of magnetite as the chief dark constituent. The phases rich in magnetite appear as "schlieren" among the more normal ones. In them the albite mostly seems to be almost pure, and the content of magnetite is very high, rising to 30 per cent. or more. Other primary con-

stituents make up one or a few per cent. Nodules are common and usually consist of albite; there are no light zones around them. The structure of the rock is characterized by the fact that the magnetite is, as a rule, squeezed in between the feldspars.

The author proposes the name *magnetite-syenite-porphyry* for magnetite-bearing rocks of this kind. The name ore-porphyry has been used by Löwinson-Lessing for a similar but more local

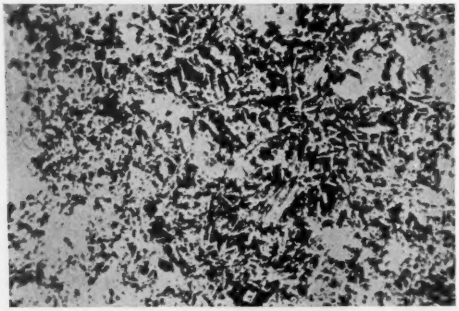

FIG. 67. Thin section of magnetite-syenite-porphyry. Ordinary light, magnified thirty-five times. White is albite, black is magnetite.

occurrence in Ural, but the author thinks it necessary to introduce a name more in correspondence with the common petrographic terms.

On Hopukka, a mountain situated about four and a half kilometers northeast of the summit of Luossavaara, the porphyries just described continue, the magnetite-syenitic phases being, however, not so common but often exceedingly rich in magnetite. The Hopukka rocks show more pronounced effusive characters than the hitherto described rocks of the district and often show interesting skeleton forms of the magnetite in the groundmass. On the eastern slope of the mountain there occurs a reddish gray porphyry with quartz amygdules, rather differing from the other rocks. Part of these contain as chief constitutent a feldspar similar to anorthoclase. The same is the case with the partly agglomeratic porphyries on Välivaara, somewhat more to the

northeast. The same zone of porphyries seems to be represented by scattered outcrops continuing for about two kilometers further to the northeast, but as the place of this group in the sequence became known first during the examinations now carried out, they were not included in the author's field of work. They are partly amygdaloidal and agglomeratic.

Above (east of) the syenite rocks follow—on Kiirunavaara and Luossavaara—the great iron ores.[1] The immense ore body of Kiirunavaara forms the backbone of the mountain, rising as a bluish black ridge, for the greatest part naked, above the porphyries of the walls. Before the beginning of prospecting work, the ore body was exposed on Luossavaara only in the summit. The summit of Kiirunavaara reaches a height of 748 meters above sea level, or 248 meters above the lake Luossajärvi between the ore mountains; the corresponding figures for Luossavaara are 728 and 228 meters. The Kiirunavaara ore body reaches a length of somewhat more than five kilometers, three kilometers of which form the ridge just mentioned. In this ridge, the horizontal width of the ore body is 96 meters and the dip 54 degrees to the east, both figures being an average; the corresponding thickness measured at right angles to the walls is 78 meters. The Luossavaara ore is not continuous with that of Kiirunavaara. Its length is about 1.2 kilometers, the dip is 65–70 degrees to the east, and its maximum width 50 meters. The contacts of the ores with their foot wall rock are on the whole rather sharply defined. Dikes and veins of magnetite sometimes run out from the ore body and intrude the porphyries, this being especially the case on northernmost Kiirunavaara where there appear breccia-like phenomena: fragments of porphyry in a matrix of ore. The fragments are sometimes completely altered to a hornblende felt. Part of the syenitic dike porphyries are brecciated in this manner, but the great dike younger than the ore body cuts right through the breccia zone, thus showing the brecciation to be of a very early date, most probably simul-

[1] The size and shape of these deposits, and other features of more technical interest, are best described by Hj. Lundbohm, in "Iron Ore Resources of the World," Stockholm, 1910.

taneous with the formation of the ore body. The hanging wall contact is even more sharply defined. On Luossavaara, the hanging wall rock carries very numerous ore fragments (see below), but on Kiirunavaara the fragment-bearing zone occupies a higher level, and near the southern end of the mountain there are veins of ore in the wall rock.

The predominating ore mineral is magnetite, hematite occurring only in very subordinate quantities. The ore is generally very finely crystalline or dense, hard and shows extensive jointing. Apatite is the most important barren constitutent, both quantitatively and from an economic point of view. Further there occurs augite, amphibole, and more rarely biotite, titanite, tourmaline (only very near the contacts) and zircon in microscopic grains. The TiO_2 per cent. is usually about 0.5% or less, the sulphur content is practically nil. On the weathered ore ridge of Kiirunavaara, the differences between varieties with differing apatite content or different structure are admirably exposed. The apatite occurs in extremely varying quantities; near both ends of Kiirunavaara and in some parts of Luossavaara there are areas where the phosphorus percentage runs below the Bessemer limit, but in general it is much higher. The apatite is now very finely distributed throughout the magnetite mass, now concentrated in patches and streaks or rather often in very irregular masses reaching more than a meter in diameter or in bands running, on the whole, parallel to the general extension of the ore body. The boundaries of these apatite concentrations towards the surrounding ore are sometimes very vague, sometimes distinct, very often they enclose fragments of ore. The apatite is finely crystalline, white or pinkish. The concentrations often carry a high percentage of evenly distributed magnetite, and great areas of the ore surface show a "schlieric" alternation of ore phases with different apatite contents. A very interesting fact has already been described by Stutzer:[1] When close to apatite concentrations the ore is often much lower in apatite than at a greater distance from them. The apatite is a fluorine apatite.

[1] "Neues Jahrb.," Beil. Bd., 24, 1907, p. 548.

The microscopic examinations of the ore shows that the magnetite generally has crystallized before the apatite. When this is not the case, there sometimes arises a rather regular alternation of bands of ore rich in apatite and of pure apatite. In some apatite concentrations a beautiful fluidal structure of the trachytoidal type has been found. A rather common and very interesting phenomenon in ore rich in apatite is the skeleton development of the magnetite. The structure is quite identical with that of some Hopukka porphyries, although the size of the skeletons is much greater in the ores. Of the other minerals occurring in the ores the augite only needs be mentioned here. It occurs within some very elongated zones, one following the foot wall in some considerable parts of the mountain, the other running more within the ore body. The augite is optically quite similar to that of the syenite rocks, and like that it is very often uralitized. Within the zones just mentioned, the ore is very rich in tabular augite and uralite crystals, which are distributed in an ophitic manner in the magnetite mass.

The quartz-porphyry forms the bed-rock on the eastern slopes of the two ore mountains and within the main part of the municipality of Kiruna. It is always a distinctly porphyritic rock carrying numerous rounded feldspar phenocrysts, about one centimeter in size, but no phenocrysts of quartz. The color of the feldspar is generally red, while the mostly dense groundmass is red, grayish red, or sometimes dark gray. The feldspar forming the phenocrysts is perthitic, the plagioclase component being albite. The groundmass is much more fine-grained than that of the syenite-porphyries, and consists of feldspar, quartz and some magnetite. The structure is microgranitic or micropoikilitic, in some cases spherulitic. The quartz content of the rock is 15–25 per cent., the magnetite content may sometimes rise to 10 per cent. or more.

On Luossavaara, and some kilometers to the northeast of this summit there is an agglomeratic zone within the quartz-porphyry, carrying fragments of syenite rocks and of different varieties of the quartz-porphyry. Close to its eastern border, especially on

and northeast of Luossavaara, the quartz-porphyry is interwoven with dikes and veins of finely crystalline apatite. These dikes, some of which show a thickness of more than one meter, are generally sharply defined towards the surrounding porphyry and very rich in angular fragments of the same. The apatite is in every respect quite similar to that occurring in the ore bodies. Some dikes are very rich in magnetite and hematite, and then the mixture of these two minerals and the apatite gives rise to structures similar to those of ore phases rich in apatite. The dikes are often striped by alternating bands of ore and of pure apatite.

FIG. 68. Dike showing alternating bands of magnetite (black) and apatite (white). The hammer lies on porphyry, which appears gray.

Some dikes contain much tourmaline, and quartz and albite are sometimes seen. Flow-structures occur, and orientated intergrowths of the minerals are rather common. On eastern Kiirunavaara there occur small "schliere"-like dikes of magnetite. There are also some very nonhomogeneous ore bodies rich in apatite, surrounded by the quartz-porphyry. Fragments of apatite-

bearing ore quite similar to that of Kiirunavaara are common in some parts of the quartz-porphyry area, and are especially well exposed on the summit of Luossavaara. They are often angular, but sometimes evidently fused.

On the eastern slope of Luossavaara there occurs east of the quartz-porphyry a relatively narrow band of magnetite ore rich in apatite, called the "Rektor" ore. It carries some albite, and its general characters point to a close relationship to the apatite dikes. The same is the case with some ore bodies somewhat more than two kilometers further to the northeast, within the so-called Nokutusvaara ore field, which perhaps occupies the same level. More to the northeast within the same field, the bed-rock is a syenite-porphyry whose relations to the other rocks of the region are unknown. This porphyry contains "schliere"-like segregations of magnetite ore rich in albite and apatite.

On Luossavaara there occurs a peculiar quartz-feldspar rock, resting on the "Rektor" ore, or immediately on the quartz-porphyry. This rock is regarded as the lowest member of the Hauki complex. It seems to be a quartz-porphyry tuff, but differs widely from the quartz-porphyry described above. It is strongly silicified. Above it follows the series of mainly quartzitic rocks which, as stated above, show a very strong silicification and probably are of tuffogeneous origin. These rocks carry hematite ore which sometimes seems to be of epigenetic origin, but sometimes perhaps is sedimentarily deposited. Interesting is the barite, albite and orthite content of these quartzose hematite ores. They are very evidently the results of late-volcanic processes, but the material obtained from the field of work of the author is not enough for the explanation of the details of their deposition. One may expect better data from the works on the whole Hauki complex which are now being prepared.

In the eastern district, the dominating rock is a quartz-porphyry, chemically identical with that of the western district, but differing with regard to the structure. The feldspar phenocrysts are smaller and generally less numerous, and the groundmass is

somewhat more coarse-grained and granulitoid. This latter structure may perhaps be the result of contact metamorphism. The porphyry is best exposed at the hill of Tuolluvaara, where it contains dike-like or irregular ore masses with a thickness sometimes rising to nearly 20 meters. The ore bodies send out innumerable dikes and offshoots in the wall rock which thus becomes quite interwoven with dikes and veins. The ore is, on the

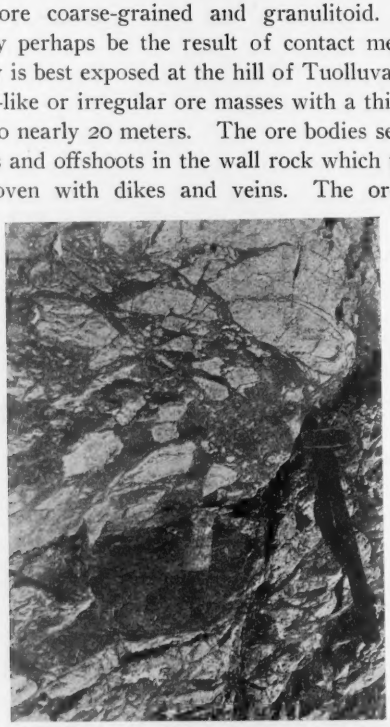

FIG. 69. Magnetite dikes in quartz-porphyry, Tuolluvaara.

whole, lower in phosphorus than that of Kiirunavaara and Luossavaara. It is more granular than these ores and carries, besides apatite, amphibole and sometimes biotite.

Five kilometers north of Tuolluvaara, on a mountain called Sakaravaara, which marks the northern end of the eastern district, there occur syenite-porphyries allied to the soda greenstones, and a rather acid quartz-porphyry with quartz phenocrysts. This porphyry seems to form a nearly horizontal bed, lying above the syenite-porphyries. Except on Sakaravaara, the quartz-porphyry of Tuolluvaara is the predominating rock throughout the eastern district.

In the theoretical statements, the chemical characters of the igneous rocks described are first discussed. The general features point to an alkaline character, this being seen among other things from the fact that the analyses as a rule belong to the peralkalic rangs in the American system, the quartz-porphyries belonging to the subrangs liparose and kallerudose, while the syenite rocks mostly are umptikases or ilmenoses. Also the 5th subrang of umptikase is represented, the persodic character being especially pronounced in the magnetite-syenite-porphyry; because of that the writer proposes the name *Kirunose* for this subrang. Despite this alkaline character of the rocks, there are found no alkali rocks in a proper sense, carrying dark alkali silicates or feldspathoid minerals, but some altered soda greenstones may originally have contained some mineral, of these kinds. A special attention is given to the magnetite-syenite-porphyry, and the author mentions the other occurrences of this kind in Lapland and a case from Ural, described by Högbom and more in detail by Löwinson-Lessing.

The origin of the nodules is discussed much in detail. Bäckström[1] has explained them as vesicles in the lava, filled by a pneumatolytic action younger than the crystallization of the rock. The present author, on the other hand, is of the opinion that they form concretionary bodies in the porphyries and have crystallized under igneous or aqueo-igneous conditions, and pass into the normal groundmass on one hand, and into true vesicles on the other hand. Among the numerous phenomena referred to as arguments for this opinion may be mentioned the occurrence of the "embryonal nodules," and the nature of the light rings which may here be summarized, so that the composition of a pinkish feldspar rock, its dark nodules included, is the same as that of a gray porphyry without nodular structure.

As regards the metamorphic processes within the region, the author has arrived at the result that they have been comparatively slight, the rocks having as a rule still kept their original structure rather intact. As an example may be mentioned the

[1] *Op. cit.*

circumstance that the quartz grains show no or only exceedingly slight crushing phenomena. A short survey is also given of the formation of the uralite and of other amphibole of secondary origin.

A very important point is the mode of eruption of the igneous rocks. While Lundbohm and Bäckström[1] regard them as effusives, Stutzer[2] considers them as intrusives, giving some arguments for this view. The author discusses every one of these arguments and cannot find any one of them convincing. Moreover an intrusive origin for these rocks is utterly incompatible with the whole geology of the district. No one of those who have studied the general geology of the tract and not only the ore deposits is in doubt in this case. As mentioned above, the author regards the syenite rocks as probably formed by one immense outflow of viscous lava, while the quartz-porphyry may possibly consist of flows very little different in age and separated by the Luossavaara agglomerate. The porphyries of the eastern district are probably mainly effusives, but no decisive proofs for this view can be obtained.

Lastly, the author takes up the question of the origin of the iron ores. This is of course, interesting as may be the geology of the region also in other respects, the main problem. Especially is it true for the monograph now in question for it has no direct bearing on the problems of Precambrian stratigraphy as will have the monographs on the partly sedimentary complexes. The author gives a short review of the different explanations proposed, and summarizes the results of the previous literature in this way: Only two chief theories can be considered, the others being already proved to be wrong. The magmatic theory was first very vaguely proposed by Löfstrand, then more decidedly by Högbom, chiefly with regard to the similar ores in Ural, and lastly very decidedly by Stutzer, who regards the ore as "eine gewandute magmatische Ausscheidung." Against this theory stands the pneumatolytic-sedimentary one, proposed by Bäck-

[1] *Op. cit.*
[2] *Op. cit.*

ström and defended by De Launay.[1] According to this theory, the ore should be deposited at the surface from gases and hot solutions.

The author calls the ores magmatic, but as regards the nature of the differentiation process as well as the mode of eruption he tries to enter more into detail than Högbom and Stutzer have done, and in both subjects his opinion comes somewhat nearer that of Bäckström. The arguments for the magmatic theory are first enumerated: All the constituents of the ore (the rare tourmaline possibly excepted) appear also as primary constituents of the surrounding igneous rocks. Especially to be emphasized is the fact that the augite of the ore is similar to that of the rocks, and that it is rather an igneous mineral. The structures of the ore furnish the most important proofs. The fluidal structures are surely primary, as they appear in ore certainly not influenced by a metamorphism capable of giving rise to a secondary structure of this kind. The structure of the augite-bearing ore, which shows an ophite-like distribution of the silicate, is a good magmatic structure and can hardly be explained in any other way. The ore showing skeleton forms of magnetite is also a very important phenomenon. The identity between this structure and that of some porphyries is perhaps the most decisive proof of the igneous origin of the ores. The geological mode of occurrence of the Tuolluvaara ores is very strongly in favor of the magmatic theory, while concerning Kiirunavaara and Luossavaara only the ore dikes in the immediate foot wall can be referred to. As on Kiirunavaara these dikes, however, are shown to have been formed at least practically at the same time as the ore bodies themselves. They may therefore be also counted as important arguments. As an argument against the pneumatolytic-sedimentary theory may be pointed out the fact that, if the iron had emanated as halogen compounds, the enormous masses of acid ought, during their escape, to have left some traces in the foot wall rocks. According to the author's opinion, the most important argument for this theory becomes insignificant, as the nodules no more can be pointed out as proofs of a

[1] *Annales des Mines*, 1903.

strong fumarolic action after the complete solidifying of the foot wall rocks.

While the author regards the magmatic origin of the ores as proved, he is not so sure as to the nature of the differentiation processes which have resulted in this product. The magnetite-syenite-prophyries are cited as showing that syenite magmas can carry an iron content comparable with that of gabbroid rocks. A comparison between the ores at Kiruna, and the well-known titaniferous ores occurring in gabbros, anorthosites and related rocks, shows some important differences, especially when regarding not only the main ores at Kiruna but also the apatite dikes, the "Rektor" ore, etc., which must have a similar origin. The case is that these ores show some pneumatolytic features which are totally wanting in the titaniferous ores. From this fact the author draws the conclusion that the ores "represent the last crystallizing parts (*i. e.*, the parts having the lowest temperature of crystallization) of the series in which the differentiation of the original parent magma has resulted." "The main ores which are almost free from 'pneumatolytic' substances—except the apatite—must have crystallized under magmatic conditions, similar to those under which the rocks were formed; the apatite dikes, though having magmatic structures, must be akin to pegmatites. The hematite ores are not igneous and perhaps not eruptive in a proper sense, though their deposition may be regarded as one of the last phases of the volcanic activity."

The author reviews some examples of magmatic and contact deposits, which probably are of the same nature as the Kiruna ores, and points out the very great probability of the existence of a differentiation type quite different from the titaniferous ores, *i. e.*, that called by Leith the "pegmatite type," to which, according to the opinion set forth above, the Kiruna deposits are to be assigned.

With regard to the mode of eruption of the Kiirunavaara and Luossavaara ores, the author is of the opinion that they have been extruded as superficial lavas; the local existence of small ore veins in the hanging wall of Kiirunavaara is probably due to after action.

THE PARAGENESIS OF BRITISH ORES.

A. Moncrieff Finlayson.

INTRODUCTION.

In a previous paper I gave the results of observations on the paragenesis of minerals in the lead and zinc veins of Great Britain.[1] The present paper summarizes the results of more extended work, embracing tin, copper and lead-zinc ores, and their associates. The chief method employed was the examination of polished specimens in reflected light, thin sections being also sliced in the case of transparent minerals. The latter method was found valuable for observations on metasomatism, which is a common phenomenon with some of the minerals, and which throws much light on the order of deposition. Field examination, and the observation of hand-specimens, give very unreliable results, owing to the rearrangement and recrystallization of minerals since their primary deposition, and to the difficulty of eliminating the effects of secondary alteration. Further, brecciation and recementation of the ores on a large scale is frequent in many vein-districts of Great Britain, and this also obscures the normal order of deposition. The earlier workers on the Cornish tin veins, notably J. Carne and W. J. Henwood, endeavored to deduce the order of arrival of the ores from observing the succession in banded and "comby" veins. But frequent anomalies and extensive brecciation render this method precarious. Likewise, the successions observed in the handsome crystal-groups which adorn museum cabinets, are valueless in the study of paragenesis, when compared with the results of microscopic work on selected ores.

The veins of Great Britain offer several well-marked types. Lead-zinc veins, with fluorspar, calcite and barytes in varying

[1] "Ore-Deposition in the Lead and Zinc Veins of Great Britain," *Quart. Journ. Geol. Soc.*, LXVI., 1910, p. 313.

proportion, are widely distributed. Tin-tungsten veins, with chalcopyrite, are confined to the Cornwall and Devon area, and copper veins occur, in addition, in scattered localities in the other districts of lead and zinc ores. The localization of copper ores, in comparison with the wide distribution of the more mobile lead-zinc ores, is a striking feature. The minerals may be considered in three groups, namely, (1) the tin-tungsten phase, with its pneumatolytic associates; (2) the copper phase, or phase of deep sulphides, accompanied by gold, and frequently by rare minerals, and (3) the lead-zinc phase, or phase of shallow sulphides. The copper phase is essentially transitional, bridging the gap between the ores of the other two phases.

THE TIN-TUNGSTEN PHASE.

The minerals of this phase, whose relations were chiefly examined, included cassiterite, tourmaline, magnetite, apatite, fluorspar, wolfram, scheelite and arsenopyrite. The history of ore deposition in Cornwall has been complex, and a microscopic examination of the ores frequently reveals several stages of mineralization alternating with brecciation and reopening of the veins.[1]

Of the above minerals, the two earliest are in general apatite and magnetite. Apatite occurs commonly in prismatic crystals which may be enclosed indifferently by magnetite, tourmaline, or cassiterite. Cassiterite is sometimes seen moulded on apatite, and fine needles of apatite are frequently enclosed in magnetite. The steel-gray magnetite, which may develop a gridiron structure with polishing, generally occurs in isolated grains and crystals, but both tourmaline and cassiterite were observed deposited round it.

Cassiterite and tourmaline come next in order. The two minerals are sometimes intergrown, and appear to be practically contemporaneous, but they tend to crystallize out separately.

Fluorspar, in characteristic cubes, is generally later than cas-

[1] J. S. Flett in "Summary of Progress for 1902," Geol. Survey Great Britain, London, 1903.

siterite and tourmaline, and continues to appear along with the latest minerals of this phase. It has a strong tendency to develop by metasomatic replacement, and was observed replacing the fluor-apatite in thin sections.

Wolfram in most cases follows cassiterite, and may be seen deposited on this mineral, as well as on apatite and magnetite. Small cassiterite needles were observed enclosed in crystals of wolfram, and one specimen showed threads of wolfram penetrating and partially replacing magnetite.

Scheelite appears to be, in nearly every case, of metasomatic origin. Thin sections showed scheelite with residual grains of apatite enclosed in it, while scheelite is sometimes seen deposited on apatite. Specimens of wolfram and scheelite in contact generally show the scheelite spreading along the cleavage planes of the wolfram, and replacing the darker mineral. This appears to be one of the chief modes of formation of scheelite in the Cornish veins.

Arsenopyrite is a persistent mineral, associated with nearly all the other ores of these veins. It is, however, generally deposited on the heavy minerals, and is distinctly later than both cassiterite and wolfram. It is sometimes metasomatic after wolfram. It is the characteristic sulphide of the pneumatolytic phase, and serves, paragenetically, to connect the ores of this phase with those of the succeeding copper phase.

The general order of deposition of the minerals here observed is as follows: (1) apatite, (2) magnetite, (3) cassiterite and tourmaline, (4) wolfram, (5) scheelite, arsenopyrite, and fluorspar. The relations of the last three minerals are not very clear, as they generally form independently. All three are prone to metasomatic formation from the older minerals. Fluorspar was observed in small cubes replacing granular scheelite, but it is doubtful if this indicates the normal order of formation. The reverse change is equally possible. Scheelite, it may be noted, is confined to this phase, while fluorspar extends into the succeeding phases, and is particularly abundant with galena.

THE COPPER PHASE.

Chalcopyrite is the characteristic mineral of this phase. Pyrrhotite accompanies it in some localities, while arsenopyrite may also occur. Pyrite is sometimes the dominant sulphide, as in the pyritic ore bodies of Avoca, Co. Wicklow, but is often absent. Rare minerals may occur in this phase, and are frequent in the Cornish area, including pitchblende, and the subordinate sulphides of bismuth, cobalt, and nickel.

When pyrite is present in quantity, it is generally the earliest of these minerals. Thus, in the dense pyrite ore of the Avoca deposits, chalcopyrite occurs as grains and irregular strings running through the mass of pyrite. In this ore, also, galena and blende are found deposited on or enclosing pyrite. Otherwise, pyrite is one of the last, and least abundant, of the minerals of both this and the next phase. In the normal copper and lead-zinc veins, it is found only in small quantities, deposited on any or all of the other sulphides. In many such cases, indeed, it is a mineral of secondary origin. The relative abundance of pyrite seems to have affected its place in the order of deposition. Its relation to pyrrhotite was not observed.

Arsenopyrite is one of the later minerals of this phase, and is found enclosing chalcopyrite. Microscopic examination of some specimens showed grains and partially formed prisms of pale arsenopyrite replacing massive corroded pyrite. This may have been an effect of secondary alteration, but as a rule arsenopyrite appears later than pyrite, although it crystallizes also in deeper zones where pyrite is not found.

Of the two minerals chalcopyrite and pyrrhotite, the latter is the earlier. The light bronze pyrrhotite occurs in irregular grains and masses, enclosed in yellow chalcopyrite, and frequently traversed by strings of chalcopyrite along minute fractures and in solution-cavities. As already mentioned, chalcopyrite occurs traversing pyrite, while it may also be enclosed in or wrapped round by steel-white arsenopyrite.

Sulphides of bismuth, nickel, and cobalt occur rarely and in small quantities in the British vein districts, but they show a

general tendency to accompany chalcopyrite and its associates. No satisfactory specimens could be secured to show the relations of these minerals to one another, but as a rule they are later than and deposited on chalcopyrite. Some granular masses of cobaltite were seen enclosing crystals of chalcopyrite.

When galena and blende are present, they are invariably later than chalcopyrite and pyrite. With the appearance of lead and zinc ores, we pass to the third phase.

THE LEAD-ZINC PHASE.

The minerals characteristic of this phase are galena and blende, with some chalcopyrite. Calcite and some quartz, fluorspar, and barytes are the common gangue minerals. Of the sulphides, chalcopyrite is the oldest. It occurs generally in well-formed crystals, on which the other two sulphides are moulded. Frequently, granular masses of galena, as well as of blende, enclose scattered crystals of chalcopyrite. This mineral appears to belong to a distinctly older stage of deposition than galena and blende. The latter sulphides are often intergrown and exhibit variable relations. In most cases, however, blende is the older, and occurs as rounded or corroded crystals which are enclosed in galena.

Quartz and calcite occupy no definite position, so far as can be ascertained. They have been deposited in varying amounts at all stages, and occur equally with the earlier and later sulphides. This is especially the case with veins in the limestone districts, where calcite is the prevailing gangue, and has been deposited at different times, both during the primary filling of the veins and during subsequent rearrangement.

In the lead-zinc veins, pyrite and marcasite, with arsenopyrite, are the last minerals in the sequence, and appear generally as crystals deposited on any of the other ores. They appear in these circumstances, however, to be the result of secondary processes. Indeed, it is difficult to assign a definite position to pyrite, as it occurs associated with nearly all the other sulphides here considered, and its relations are often conflicting. As a

primary mineral, however, it is certainly one of the older sulphides.

In the case of barytes, the most significant fact is the tendency for barytes and galena to separate into different parts of one and the same vein. Veins with a gangue of barytes are seldom rich in galena, and *vice versa*. Exceptions may be seen, but this rule generally holds good, that the appearance of barytes in quantity heralds an impoverishment with respect to galena. It is, indeed, difficult to secure specimens which show the two minerals in intimate relation. It appears evident that both minerals were practically contemporaneous, and that the local conditions which favored the deposition of the one were unfavorable to the other. The formation of barytes seems to require oxidizing conditions, under which galena would not be deposited. Barytes, in general, seems to have been approximately contemporaneous with galena and blende. It sometimes encloses scattered crystals of chalcopyrite.

Fluorspar, in the phase under consideration, is essentially a metasomatic mineral. It is practically confined to those veins which traverse limestone or other calcareous rocks. In such

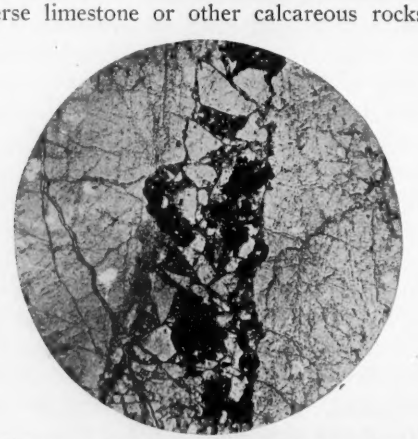

FIG. 70. Irregular crystals of galena replacing fluorspar along a fissure filled with brecciated fluorspar. Rookhope mine, Weardale, Durham. Transmitted light. × 30.

cases it is very abundant. Thin sections of the gangue and of the adjoining country rock show the replacement of limestone, dolomite, and recrystallized calcite by fluorspar. The fluorspar occurs generally in cubes which spread into the rock, along cracks and fissures, completely replacing it, with the formation of a compact mass of the ore. It is sometimes seen enclosing chalcopyrite, while its priority to galena is seen in its replacement by this mineral. This mode of deposition of galena is often seen under the microscope, especially where the fluorspar has been crushed or fissured by movement. Galena then appears in scattered grains along these fissures, gradually replacing the fluorspar and forming a compact mass of granular ore. The galena thus formed rarely shows good crystal outlines. Blende also, but to a lesser extent, may replace fluorspar in a similar manner.

SUMMARY.

The results of the above observations are here tabulated. In some cases, the observed relations are fairly definite, and leave little room for doubt. In other cases, however, the relations may be open to more than one interpretation. The order given is believed to be correct in the main, though exceptions are frequent. The disturbing element of secondary alteration, to which many of the exceptions are due, was excluded, as far as possible, in the collection of specimens. Pyrite and arsenopyrite are the most difficult minerals to deal with, as they occur, to a certain extent, in all the three phases studied. The positions assigned to them in the appended list must be regarded as only provisional, but they indicate their relations in most of the specimens examined.

3. Lead-Zinc Phase .....
- 4. Galena. } Barytes.
- 3. Blende. }
- 2. Fluorspar.
- 1. Chalcopyrite.

2. Copper Phase .....
- 4. Arsenopyrite.
- 3. Chalcopyrite.
- 2. Pyrrhotite.
- 1. Pyrite.

1. Tin-Tungsten Phase ....
   5. Arsenopyrite, scheelite, fluorspar.
   4. Wolfram.
   3. Cassiterite, tourmaline.
   2. Magnetite.
   1. Apatite.

The physical conditions attending ore-deposition in the different phases undoubtedly affect the paragenetic relations of the minerals. These relations can only be satisfactorily determined after the elimination of accidental and anomalous cases by more extended work. The persistence of fluorine, from the earliest apatite, to the much later fluorspar associated with galena and blende, is worthy of note, and supports the view that the ores have all been derived from one and the same process of magmatic extraction, the magma being probably granitic.

The following cases of metasomatism among the primary ores, were all observed in the present work. Pseudomorphs, which are mostly of secondary origin, are not included.

Apatite to scheelite and to fluorspar.
Scheelite to fluorspar.
Calcite to fluorspar.
Magnetite to wolfram and to arsenopyrite.
Wolfram to arsenopyrite.
Wolfram to scheelite.

These cases have all an element or radical in common. It is in such circumstances that the order of deposition is most clearly shown. Minerals such as cassiterite and tourmaline, on the other hand, are frequently intergrown, but this is seldom the case with the various sulphides, which generally show a definite order of deposition, whether metasomatic replacement has occurred or not.

SECONDARY MINERALS.

Products of secondary alteration in the ores here examined are numerous and have been the subject of much study by mineralogists. In particular, two minerals, which are concluded to be of secondary origin in all cases, were examined in the present work. These are native silver, and chalcocite.

A considerable number of specimens of galena, taken from deep workings, were examined, but in none of these could any silver or silver-bearing mineral be identified by any etching reagent. All the unaltered argentiferous galenas examined appear to carry their silver (in amounts up to ten ounces per ton of galena) either in a state of extremely minute dissemination or in isomorphous combination with the galena. On the

FIG. 71. Veinlets of secondary native silver (dark) traversing galena. Ore from Leadhills, Scotland. Reflected light. ×400.

other hand, some specimens of highly argentiferous galena, taken from within the zone of secondary enrichment, showed under the microscope threads and strings of native silver occupying cleavage-cracks in the ore. In all the specimens secured, the differentiation of silver in galena is undoubtedly an effect of secondary alteration.

On the other hand, the cupriferous pyrite of the Avoca deposits (Co. Wicklow), and of Parys Mountain (Anglesea), carrying 1 or 2 per cent. of copper, contains the copper as fine grains and strings of chalcopyrite traversing the pyrite, exactly as in the lean pyritic ore of Rio Tinto.[1] The Avoca and Parys

[1] A. Moncrieff Finlayson, "The Pyritic Deposits of Huelva, Spain," ECON. GEOL., V., 1910, p. 417.

ores have, further, been profoundly enriched, with the formation of much chalcocite. This first appears round the chalcopyrite grains, replacing them, and growing into larger irregular bunches of chalcocite, while the pyrite becomes porous and corroded. All

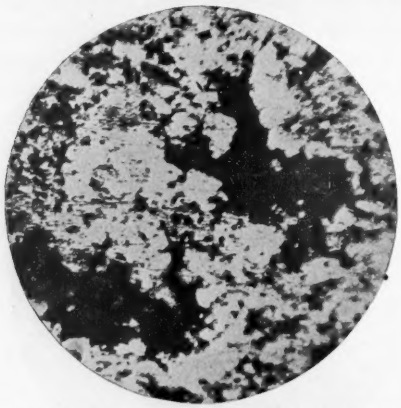

FIG. 72. Masses of secondary chalcocite (black) replacing pyrite in enriched ore. Avoca, Co. Wicklow, Ireland. Reflected light. × 100.

the chalcocite observed in these ores is of secondary origin, formed, not from copper combined with the pyrite, but from grains of primary chalcopyrite in the pyrite.

The loss of silver during the wet concentration of some lead ores, and the adaptability of certain lean copper ores to the leaching process, seem to be both due to phenomena of secondary alteration and enrichment, as indicated above. The facts strongly suggest the application of the microscope in the study of opaque minerals to problems of ore-treatment.

THE IRON FORMATION OF THE CUYUNA RANGE.

FRANCIS S. ADAMS.

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INTRODUCTION.

This article is mainly a discussion of the iron formation of the Cuyuna Range, with some reference to its relation to the general geological structure of the region. The chemical, mineralogical and physical characteristics of the different rocks making up the iron formation are discussed in their bearing on the development and origin of the ore deposits.

It is hoped that the facts here presented will assist the explorer in locating prospective ore deposits on the Cuyuna Range.

The treatment in this paper of the origin and development of the Cuyuna Range ores is along the same lines as that already worked out by Van Hise and Leith and others for the Lake Superior iron region as a whole. Methods developed by them were applied to the problem of the Cuyuna district and the nature of the development of ore bodies on this range was found to be nearly identical with that for the other ranges, differing only in one or two minor points which have been brought out.

The writer wishes to express his appreciation of the advice and suggestions given him by Dr. C. K. Leith while the article was in preparation; also to W. J. Mead for the use of certain

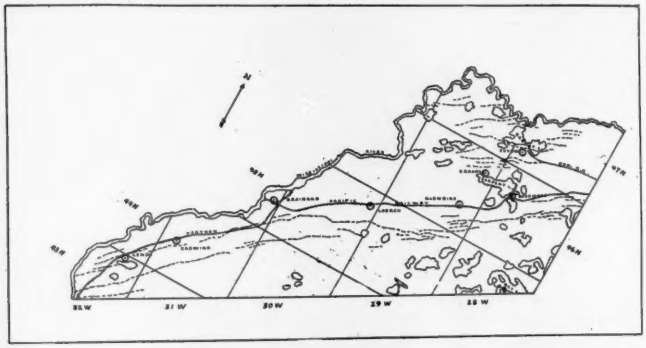


FIG. 73. Map of the Cuyuna Iron Range. The dotted lines are magnetic belts.

diagrammatic methods of treatment developed by him and to the various operators on the Cuyuna Range for the free access given to their records and data.

PART I.

A SYNOPSIS OF THE GENERAL GEOLOGY OF THE DISTRICT.

GEOGRAPHY AND TOPOGRAPHY.

The Cuyuna district lies in the north central part of Minnesota, extending in a general northeasterly and southwesterly direction across Crow Wing County into Aitkin County on the east and Morrison and Todd Counties on the west. The Mississippi River extends along the north side of the district and turning south at Brainerd, Minn., cuts across the southwestern end of the range. The exact townships into which exploration has been carried up to the present are given under the discussion of the distribution of the Deerwood formation. Reference to the

accompanying sketch map also shows the geography of the district.

That branch of the Northern Pacific railroad running east to Duluth, Minn., from Staples, Minn., passes through the entire length of the Cuyuna district. The towns along the railway which are also located on the Cuyuna range are, from west to east, Phillbrook, Brainerd, Deerwood, Aitkin and Kimberley. Randall, Lenox and Crowing on the line of the Northern Pacific from Brainerd to St. Paul also fall within the confines of the district. A recently completed branch of the "Soo" road enters the district from the southeast from Moose Lake, Minn., cutting across the Cuyuna range proper west of Kimberley on the Northern Pacific. Recently exploration has been carried on in the vicinity of the north side of Mille Lac Lake some fifteen miles south of Deerwood, Minn. Magnetic attraction in belts parallel to those already developed on the range have been found at this point but drilling has not yet proven the presence of the iron formation.

The extreme western portion of the Cuyuna district in Todd County in townships 133–32 and 133–31 has not yet been connected by drilling or by presence of continuous magnetic belts with the range proper. A gap occurs from a point west of Randall to a point near Phillbrook on the Prairie River in Todd County.

The range as a whole presents an area for exploration of some 38,000 to 40,000 acres.

The average elevation above sea level of the Cuyuna district is about 1,230 feet, or some 600 feet above the level of Lake Superior, the extremes being 1,150 feet and 1,300 feet. In other words the district as a whole has a flat level surface. The irregularities of the surface are due to small glacial hills or knolls and numerous small glacial depressions now occupied by lakes. These minor irregularities give the district a rolling topography.

The Cuyuna district is an area of glacial deposition rather than glacial erosion. No rocks outcrop throughout the entire district save a few small ledges in the southeast corner of the range in township 47–25.

THE GEOLOGICAL SUCCESSION.

Since there are no rock outcrops on the Cuyuna Range the succession of those formations known to be represented in this district can only be told by the records of the drill holes and the two shafts now sinking. Nearly 2,000 holes have been sunk on the entire district to date. Below is the geological table for the district, the formations in point of age reading from the bottom up.

Glacial Drift.	
Cretaceous	Conglomerate.
Keweenawan	Intrusive diorites and diabases.
Upper Huronian	*Slate.* *Iron Formation* (in lenses distributed through the slate). *Quartzite?* and *Quartz Schists?*

Exploration on the Cuyuna Range has not yet exposed rocks of Lower Huronian or Archean age, so nothing can be said as to their characteristics for the district.

The Upper Huronian.

The Upper Huronian sediments are the series of chief importance in the Cuyuna district, containing as they do, the iron formation member.

The Upper Huronian consists mainly of a thick slate formation composed of pyritic and graphitic stratified slates. Imbedded in this slate formation are lenses of the Deerwood or iron formation, the distribution and detailed consideration of which are taken up in another part of this paper under the heading "The Deerwood Formation." Quartzite has been encountered in two localities, seemingly underlying the slate formation.

Slate.—Most of the slate is schistose. Other portions of the slate member have suffered little deformation by flow and are non-schistose. The above, with the fact that the slate contains quartzitic, limy, and carbonaceous shaly phases, gives to the slate member a variety of appearances as encountered in different localities by drilling.

A light gray or green colored schistose slate is probably the most abundant phase of the slate member on the Range. This type is quite soft and cleavage by flowage has been developed to such an extent that nearly all traces of bedding are obliterated. Small mica flakes, developed by the extreme deformation, are scattered abundantly through the mass.

The above type of slate is met with in all parts of the district and forms the "hanging" wall to many of the ore deposits of the south range.

The phase of the slate member next in abundance is probably the black slate. This is dark, almost black, in color, shows bedding and has not been rendered so generally schistose as the green or gray slate previously mentioned. It is moreover harder than the gray green schists. It is quite graphitic and contains bands of pyrite in some localities, notably in section 16–46–28. This black graphitic pyritic phase is shown typically by drilling on section 24–47–29 northwest of Rabbit Lake. It was encountered in great abundance in the Rice River locality, northeast of Aitkin in townships 48–26 and 47–26 and in township 136–26, north from Deerwood. At Cedar Lake, between Aitkin and Deerwood, on the Northern Pacific it was also encountered. Together with the green schistose slate it is found on section 13–47–27. Southwest of Deerwood in section 36–46–29 and in sections 9–45–29 and 3–45–29 this phase is also represented, as shown by drilling. The pyrite bands are clean and range from $\frac{1}{36}$ to $\frac{1}{4}$ inches in thickness, and are characteristic of this phase of the slate.

A quartzitic slate or graywacke is locally abundant in several parts of the Cuyuna district. It is hard, can not be scratched easily with a knife, and has no cleavage. The banding is very distinct. The color is light to dark gray. The highly quartzose nature of this phase is plainly seen on examination of a drill core from it. This graywacke is typically exposed by drilling in the Rice River district, townships 48 N., R. 26 W.

In section 2–46–29 Leith and Zapffe note the occurrence of a pink, semi-translucent limestone. It is fine grained and is finely bedded. It there occurs in connection with quartz and graywacke.

Quartz in stringers, and as a filler for fissures, in the slate and in the lenses of iron formation, occurs throughout the district.

Quartzite.—We have mentioned in noting the general make-up of the Upper Huronian, that a quartzite similar to the Pokegama quartzite of the Mesabi Range has been encountered at two points in the district. One of these is in section 24–47–29, northwest of Rabbit Lake and the other is an outcrop on the northwest side of Dam Lake, in township 47–25.

Two holes drilled on section 24–47–29 penetrated 30 and 50 feet of clean unaltered quartzite. This quartzite is generally pink in color, due to iron staining. Where not stained by iron it is light or grayish in color. The quartz grains are cemented with secondary quartz and some iron oxide, giving the pink color noted above. Further drilling at this point showed that this quartzite underlies a lens of iron formation and the slate.

The Dam Lake exposure shows quartzite of the same general type as that described above. Drilling to the north of this exposure showed iron formation underlain by a schistose quartzite, which appeared to be an altered form of the quartzite just described.

It would seem then that these two occurrences show a quartzite formation underlying the slate formation in the Cuyuna district.

The Keweenawan.

The Keweenawan as represented on the Cuyuna consists of numerous dikes and irregular bosses of igneous rock cutting through the Upper Huronian slate and included lenses of iron formation.

The intrusives are mainly diorite and diabase. Some of these intrusives, as encountered by drilling, are fresh and unaltered, some show deformation, being rendered schistose and some are weathered.

These masses are all later than the Upper Huronian deposition since they all are intrusive into the slate formation. Some were intruded prior to the complex folding of the district as is attested by their schistose nature and the fact that they

show secondary cleavage similar to that of the folded slates. Some are later than the folding, since they appear fresh and non-schistose and evidently have taken no part in the complex folding of the slates. All were intruded prior to the exposure and secondary concentration of the iron formation. This is to be seen from the nature of their relation to the ore deposits.

There is an outcrop of the intrusive diabase at Dam Lake. This rock is crystalline, light gray green in color, fairly fresh, and non-schistose. Its mineral components are those of the ordinary diabase with pyrite, in numerous specks through the rock, in addition.

Cretaceous Conglomerates.

These have been encountered in only one locality, at the Pickands Mather shaft in section 8, township 45–29. They were found here in a small patch immediately overlying the rock of the iron formation. The pebbles of the conglomerate are composed of ferruginous chert, amphibole, magnetite and slaty ore. The matrix is slaty. There is no absolute proof that this conglomerate is of Cretaceous age. It is supposed to be, as it resembles so closely the proven Cretaceous conglomerate on the Mesabi Range and bears the same relation to the underlying Upper Huronian as does the Cretaceous conglomerate of the Mesabi.

Glacial Drift.

The glacial drift as has been said, covers all the rock surface of the Cuyuna district except for the small projecting rocks at Dam Lake. The thickness of the drift covering varies from 50 to 390 feet.

Starting at the southwest end of the Cuyuna Range proper in township 43–32, southwest from Brainerd, drilling in section 12–43–32 shows the drift mantle in that locality to be from 90 to 110 feet in thickness. Proceeding northeastwardly along the strike into township 44–31 we find the drift, as shown by drilling in section 22, to vary between 140 and 120 feet in thickness. Still further on in township 44–30 drilling in section 6 shows

it to have increased to an average depth of about 175 feet, varying in this locality between 148 and 200 feet.

Northeast of Brainerd in townships 45–30 and 45–29 it is from 75 to 100 feet thick. Proceeding eastward along the strike of the range the drift covering again increases in thickness. In township 46–28 it averages about 160 feet, varying between 120 and 195 feet and in township 47–27 it attains over 350 feet in depth. Eastward the drift mantle grades off again. In the northeast end of the district on the Rice River some 8 miles northeast of Aitkin it averages 120 feet in thickness.

In the Rabbit Lake district the drift is comparatively shallow, averaging about 90 to 100 feet.

Northwest of Serpent Lake in township 46–29 drilling in sections 1, 2, 10, 11 and 12 show the drift mantle in this locality to have an average depth of about 90 feet, varying from 50 to 125 feet in thickness.

In Todd County on the unconnected western extension of the Cuyuna Range the drift averages, where drilling has taken place, in township 133–32, about 135 feet in thickness.

In Becker County still further west some few holes have been drilled and here the drift mantle is very thick. Holes were sunk 390 feet without encountering rock.

This glacial drift is composed of layers of clay, dry sand, gravels and beds of quicksand with granite boulders scattered through the whole. A thin mantle of sandy soil rests on top of the drift.

DEFORMATION OF THE UPPER HURONIAN SERIES.

It is impossible in the present stage of exploration to state in detail what the structural conditions are on the Cuyuna Range. The only records we have of structure are those furnished by the belts of magnetic attraction, the drill cores, and the shaft of the Rogers Brown mine at Rabbit Lake. This shaft gives us the minor folding and faulting for a small localized section of the iron formation and bounding slates. The folding and faulting of the slates at Carlton, Minn., also give a clue to the conditions

on the Cuyuna Range since the slates outcropping at Carlton are the same as the Cuyuna slates, as has been determined by Leith.

Relations of Major to Minor Folding.

Van Hise and Leith have shown that the minor folds, small folds observed in a hand specimen or those of a foot or two in dimension bear a distinct relation to the folds of a larger order for the same locality. That is, if one observes in place a small fold of a certain type, a drag fold say, having a certain direction of strike and dip, he will find that the larger folds of that particular area, folds measured in hundreds of feet or even in miles, will be also of the drag type and will have the same direction of strike and dip as the small fold first observed. The reason for this is clear. Certain types of folding are produced by definite pressures, the directions of the pressures being responsible for the character of the fold produced. The same pressures produce the big and little folds in a definite stratum for a definite locality, hence these folds should have the same characteristics.

The similarity in type, strike and dip of the minor folds and those of a higher order can be seen again and again in the field. At Carlton this is well brought out. On the north edge of the town there is an outcrop representing a limb of a large anticline. Within this outcrop are several small folds measuring about one and a half feet. They are drag folds, pitch very gently to the east and dip about 70° to the south. On tracing out the large fold, of which the whole outcrop is a portion of one limb, it appears that it is a drag fold dipping about 70° to the south, striking east and west and pitching gently to the east. Other illustrations could be taken, as at Soudan, Minn., in the closely folded jasper formation, but space will not permit. The application of this principle to the folding in the Cuyuna district will be brought out.

Distribution and Character of the Folding in the Cuyuna Area.

The folding of the Cuyuna district as a whole is best shown by the series of nearly parallel magnetic belts, whose distribution

is shown on the sketch map. The magnetic belts indicate the truncated edges of belts of the iron formation which were exposed on their upper edges when the tops of the anticlinal folds were cut off by erosion. The minor closely parallel lines do not represent, in all probability, truncated limbs of recurring folds but small lenses or belts of iron formation at different horizons on the truncated limb of one fold. The large major belts of attraction, made up of a series of overlapping minor belts, probably indicate the limbs of the recurring major folds.

Note that the series of magnetic belts south of the Northern Pacific railway may be grouped into two main belts which start in the extreme southwest corner of the district, about a mile and a half apart, and extend in a northeasterly direction, gradually converging, till they finally merge into one belt at a point some three miles south of Klondike on the railroad.

North of the track, although the distribution does not so definitely group into a series of major belts, we have four series of overlapping belts which group themselves to form four major magnetic belts lying nearly parallel, each being separated by a distance of about a mile to a mile and a half.

Drilling along these belts of attraction has shown that the underlying rock strata are dipping steeply southeast or northwest, the dips varying from 50° from the horizontal to vertical.

Application of the principle of the relation of minor and major folding in any area, to the folding of the Cuyuna district throws more light on the character of the folding. The iron formation where it has been penetrated by the drifts at the Rogers Brown mine shows complex crenulated folding of a small order superimposed on larger folds. That portion of the formation pierced by the drifts represents a portion of a limb of a large fold. The strike of the steeply dipping beds is northeast by east and the dip is southeast about 73°. The drifts running southeast give a cross-section of this limb. On the sides of the drifts we can find cross sections of small folds, measuring from six inches to a foot, up to 3 and 4 feet. These are drag folds. Many of them dip steeply, parallel to the dip of the major limb, that is,

southeast. Their strike is northeast, parallel to that of the major limb. The throw of the small drag folds, oriented as above, is up and toward the northwest. Fig. 74 shows one of these typical drag folds. It can also be taken as representing the type of the major folding.

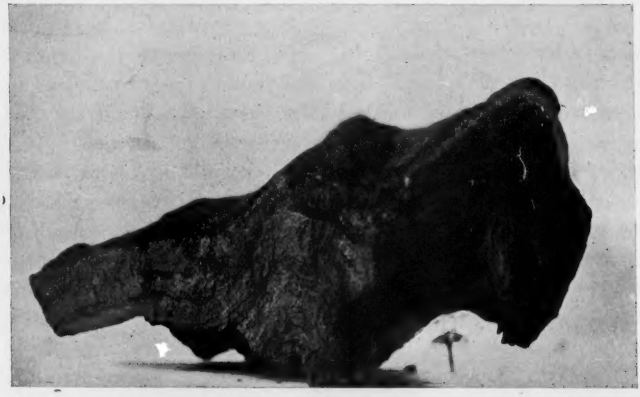


FIG. 74. Photograph of typical minor drag fold of the Deerwood formation. This illustrates the type of the major folding. Cross sectional view.

It seems then that the large fold, one limb of which has been cross cut by the mine drifts, is of the drag type with a throw towards the northwest.

One phase of the major folding of the Cuyuna is made plain by the above facts. There are present recurring folds apparently of the drag type striking northeast and southwest, with the upthrow on the northwest.

Deformation by Flow and Fracture.

As already remarked, much of the slate of the Cuyuna district has been rendered schistose. This is due to deformation of the rock by flowage rather than fracture. Some of the slates have secondary cleavage so well developed that all trace of the original bedding is gone. In other words they are very schistose.

Not only the slates but the older intrusives have suffered deformation by flowage, that is, they are schistose.

Now note that part of the slate formation and as a rule the younger intrusives are comparatively non-schistose.

These facts seem to point to the fact that most of the acute folding of the slates of the Cuyuna district was due to the intruding of numerous masses of igneous rock and that the schistosity developed in much of the slate was due to these intruding masses. If the folding and secondary cleavage had been developed under purely anamorphic conditions due to the depth at which the rock was buried then one would expect to find all the slates schistose and no marked local variations; but if the folding and schistosity was largely due to the intrusions of many large masses of igneous rock then one could look for local variations in amount of schistosity developed and for comparatively non-schistose conditions in any locality free from immediate intrusions. The latter conditions hold in the Cuyuna Range. Again we find some of the intrusives schistose, others non-schistose. The earlier schistose intrusions were probably rendered so by the intrusions of the later masses of igneous rock.

Deformation by pressure alone may have had some part in the development of the acute folding and schistosity of the slate formation; but it seems probable that most of the deformation was due to the intruding masses.

Deformation by fracture has also played a large part in the deformation of the Cuyuna sediments. The same conditions that caused the softer members to deform by flowage caused the hard resistant portions of the sediments, as the quartzite, to deform by fracture. Fracturing is present throughout the slate and iron formation.

(To be continued.)

STRATIGRAPHIC RELATIONS OF THE LIVINGSTON FORMATION OF MONTANA.

PART III.

R. W. Stone and W. R. Calvert.

AREA NORTH OF THE CRAZY MOUNTAINS.

On the divide between Sixteenmile Creek and Musselshell River at Summit, ledges of hard tuffaceous sandstone occur in the Eagle and in the upper part of the Colorado. The stratigraphic position and age of these tuffaceous beds is proved by the presence of the white Eagle sandstone just above them and by the collection of the following fossil invertebrates from the beds in question:

SHELL FROM ¼ MILE S.-W. OF SUMMIT.

Avicula nebrascana E. & S. *Baculites compressus* Say?
Cyprimeria sp.

These shells occur in the second brown ledge beneath the prominent white (Eagle) sandstone in the ridge southwest of Summit station. Of them Stanton says:

> The fossils seem to be more closely related to the Montana group fauna than to that of the Colorado, and thus indicate that this lower sandstone should probably be included in the Eagle.

In these same beds about 300 yards southwest of Summit station Stone found the impression of a plant which Knowlton considers to be a new species of *Ficus*. Concerning it Knowlton says:

> As this appears to be a new species it cannot be used in fixing age, though I should incline to regard it as probably not older than Montana.

About one-eighth mile west of Summit and 300 to 400 feet above the supposed Eagle sandstone Knowlton collected the following leaves (No. 5514):

Populus cretacea Kn.
Sequoia reichenbachi (Gein.) Heer?

Several fragments of indeterminable dicotyledons.

Knowlton says:

> The species first given above has not been found outside the Judith River, and the conifer is common in, but not confined to, the same horizon. The age should be either Judith River or something very near it.

On the east side of the anticline which brings up Colorado shale at and east of Summit the Eagle is exposed with two gray sandstone members. Where it crosses the railroad about three-fourth mile east of Dublin siding the following collection was made by Knowlton, Stanton and Campbell on the south side of the track and about 25 feet above the Eagle sandstone.

SHELLS FROM JUST ABOVE EAGLE SANDSTONE.

(Sec. 17, T. 7 N., R. 9 E.)

Ostrea subtrigonalis E. & S.
Anomia gryphorhyncus Meek.
Modiola sp.
Panopaea simulatrix Whiteaves.
Corbula subtrigonalis M. & H.
Melania insculpta Meek?

Stanton says this is essentially the brackish-water fauna of the Judith River, but it occurs also in the Claggett of this region. At the same locality and stratigraphically 625 feet above the Eagle in sandstone lithologically like Livingston Stanton collected the following shells:

Sphærium sp.
Physa sp.
Hyalina? evansi M. & H.
Goniobasis? subtortuosa M. & H.
Goniobasis? sp.

This collection he pronounces as of Judith River age.

It was shown in the previous chapter that a marine fauna is contained in tuffaceous or Livingston beds on the west side of the Crazy Mountains. The collections just enumerated are fresh- and brackish-water forms and were found in beds of volcanic material. To the writers this seems to be strong evidence of the Montana age of the lower portion of the Livingston forma-

tion as it occurs at Livingston, for on the evidence of stratigraphy and invertebrate paleontology the tuffaceous beds which are found on the north side of the Crazy Mountains are the same as those in which practically all of the Livington flora has been obtained on the south side of the Yellowstone and the east side of the Bridger Range.

Further evidence of the incursion of Montana faunas and floras and of the differentiation of the Upper Cretaceous formations from the Livingston formation is found a little farther east on the headwaters of the south forks of Musselshell River at the mouth of Bozeman Creek. Here in sec. 5, T. 7 N., R. 9 E., dark shale carrying undoubted Bearpaw shells is clearly differentiated from the underlying and overlying beds of strongly tuffaceous appearance and hence supposed to be Livington. This fossiliferous shale occurs about 1,000 feet above the Eagle sandstone. The following species were collected on the west side of the road running up the ravine opposite the mouth of Bozeman Creek by Stanton, Campbell, Calvert and Stone and were identified by Stanton:

SHELLS FROM BEARPAW SHALE.

(Sec. 5, T. 7 N., R. 9 E.)

Ostrea pellucida M. & H.
Chlamys nebrascensis M. & H.
Inoceramus crispi var. *barabini* Morton
Avicula nebrascana E. & S.
Avicula linguiformis E. & S.
Modiola sp.
Gervillia sp.
Lucina sp.
Protocardia subquadrata E. & S.
Protocardia sp.
Callista nebrascensis M. & H.
Callista deweyi M. & H.
Lunatia sp.
Vanikoropsis tuomeyana M. & H.

Anchura americana E. & S.
Anchura sp.
Anisomyon borealis M. & H.
Baculites compressus Say
Placenticeras Whitfield Hyatt.
Scaphites nodosus Owen.

This is a typical marine Bearpaw fauna.

At this place the thousand feet or more of beds lying between this fossil horizon and the Eagle sandstone cannot be divided on lithologic grounds into the Claggett and Judith River formations. It is possible that careful search for fossils might bring to light paleontologic evidence on which such a division could be made, but the writers are obliged for the lack of evidence to consider them as a unit on account of their uniform character. Their volcanic origin is shown by the following determination made by Calkins from thin section.

C.M. 15. Andesite tuff. From near the base of the Bearpaw; T. 7 N., R. 9 E., sec. 5. Bearpaw fossils collected above. Specimen consists of many feldspar and augite crystals, with some magnetite and rock fragments with the texture of an andesite groundmass. The rock undoubtedly is essentially a pyroxene andesite tuff.

The beds of purely volcanic origin are intercalated with sandstones and shales of marine and brackish-water deposition. The following section in which the greenish beds are for the most part tuffaceous is introduced to show the interbedding of sandstone, shale and tuff, and to show the relation of the specimen described above to the Bearpaw fossils.

SECTION IN T. 7 N., R. 9 E., FROM THE MIDDLE OF SEC. 4 TO THE NORTHEAST CORNER OF SEC. 8.

	Feet.
Sandstone and shale, greenish	260
Sandstone, massive, green	50
Concealed mostly, probably all shale, Bearpaw, marine shells (No. 609) collected near base	778
Sandstone, tufaceous, greenish (spec. C.M. 15)	300?
Sandstone, massive, green, lower part shaly	40

Shale, purple, sandy	15
Sandstone, green, thin-bedded	25
Shale and sandstone, yellow and gray	445
Shale, baked, and sills	50
Sandstone, gray, massive	25
Sandstone, green to gray, thin-bedded	30
Porphyry, coarse-grained, trachytic sill	25
Sandstone, gray, massive, soft	10
Sandstone, green, shaly	100
Sandstone, gray, massive, soft, Eagle	20

Fossils collected 2 miles below the mouth of Bozeman Creek, in sec. 34, T. 8 N., R. 9 E., show the presence of Claggett and Judith River formations, although lithologically they are difficult to recognize. Even to one thoroughly familiar with the appearance of the two formations it is scarcely possible to distinguish them in this part of the Musselshell Valley. East of Lennep however, the andesitic tuff is much less abundant and it becomes possible to recognize not only the Claggett and Judith River formations but also to separate the "Laramie" formation or "Ceratops beds" from the mass of material above the Bearpaw shale. In ranges 10 and 11 or between Lennep and Martinsdale, as the distance from the seat of greatest volcanic activity increases, the amount of volcanic material in the geologic section between the Eagle and Fort Union formations decreases and the distinctive lithologic characteristics of the marine, brackish and fresh-water deposits become more pronounced. Even farther east than Martinsdale the Claggett and Judith River formations continue to be more or less tuffaceous but the intercalated thin beds of volcanic material are thinner and less numerous than farther west.

AREA NORTHEAST OF THE CRAZY MOUNTAINS.

In the field work of 1907 on Musselshell River, Stone recognized that in place of the four post-Jurassic formations described by Weed south of the Little Belt Mountains ten formations or mappable lithologic units could be distinguished. These are the Kootenai, Colorado, Eagle, Claggett, Judith River, Bearpaw,

Lennep, Lance, and Fort Union (with its Lebo andesitic member) formations.

Lance formation has been adopted by the Committee on Geologic Names for the light-gray sandstone and variegated shale (1,000–2,400 feet thick) which have hitherto been called "Laramie" formation and "Ceratops beds." The name is from the type locality Lance Creek, Converse County, Wyo., where most of Hatcher's vertebrate fossils were obtained from beds which he called "Lance Creek beds" in *American Geologist*, vol. 31, pp. 369–375. According to the committee Lance formation will be used to replace "Ceratops beds" in Wyoming, Montana, and the Dakotas; Laramie formation is approved for Denver Basin, "Laramie" formation may be used where referring to rocks of other localities than the Denver Basin, but Lance formation supplants "Laramie" and "Ceratops beds".

In the geologic section on Musselshell River, which comprises over 5,000 feet of strata, not including the typical Fort Union, there are along the northern flank of the Crazy Mountains two groups of strata of decided Livingston aspect which have considerable thickness and geographic extent. The older of these occurs between the Bearpaw shale and the Lance formation, and the second, which was described by Stone[1] as the Livingston formation, lies between the Lance and Fort Union. The name Lennep sandstone is here applied for the first time to the beds at the base of the Lance formation. Lennep is a station on the C. M. & P. S. Railroad, at the north end of the Crazy Mountains and in the immediate vicinity of a ridge formed by these beds. The younger andesitic beds belong to the Fort Union formation and to them the name Lebo andesitic member is given. Lebo is the name of a creek in whose upper course these andesitic beds are exposed. The Lebo member is composed of 450 to 2,200 feet of dark-colored beds lying between the Lance formation and the massive gray sandstone of the Fort Union formation. The Lennep sandstone and the Lebo andesitic member are of much

[1] Stone, R. W., "Coal Near the Crazy Mountains, Montana," Bull. U. S. Geol. Survey, No. 341, 1908, p. 82.

the same material and appearance. They are composed in part of volcanic material, and had they occurred in juxtaposition would without doubt have been considered as one formation on account of their lithologic similarity.

The Lennep sandstone is composed of dark-colored tuffaceous sandstone intercalated with dark shale. It ranges from 250 to 460 feet thick and throughout much of the outcrop is dark brown en masse, which distinguishes it from the gray to black shale below and from the overlying light gray sandstone. At several places near the middle of these beds a band of brown cannonball nodules 8 to 12 inches in diameter was observed. The fossil shells found in this formation are about equally fresh, brackish water, and marine, the fresh water and marine forms occurring in separate horizons. Leaves and a marine plant, *Halymenites major* Lesq., have also been found. The Lennep occupies the stratigraphic position of the Fox Hills and like it is transitional from the marine Cretaceous to the fresh water "Ceratops beds" but sufficient fossils have not yet been obtained to make the correlation positive. The rocks along the greater part of the outcrop of the Lennep sandstone on the northeast side of the Crazy Mountains are highly tilted, a condition which, together with their greater hardness, makes a narrow crested and conspicuous hogback ridge between the Bearpaw shale valley on one side and the low relief of the soft sandy Lance beds on the other.

The tuffaceous character of the Lennep sandstone is shown by the composition of thin sections cut from specimens taken by Stone on a fork of Big Elk Creek in sec. 10, T. 6 N., R. 13 E. These specimens which are four in number, represent the more tuffaceous beds of the dark-colored sandstone. They occur stratigraphically within 100 feet above the top of the Bearpaw shale. All four specimens have the texture of sandstone but are composed almost entirely of volcanic material, and might be called tuffaceous sandstone. The following descriptions begin with the lowest and end with a specimen taken near the middle of the Lennep beds.

C.M. 97*a*. Consists of plagioclase grains and fragments of a microlitic rock, apparently andesite, stained with iron oxide and cemented with chloritic material and calcite. Might be called calcareous sandstone.

C.M. 97*b*. Same as 97*a*.

C.M. 97*c*. Consists of very abundant fine granular plagioclase and numerous fragments of andesite in a chloritic groundmass.

C.M. 97*d*. Consists very largely of fragments of microlitic rock, apparently andesite, and angular to subangular grains of plagioclase, although there is a small amount of quartz and a few fragments of pyroxene and biotite. All is cemented by chloritic material. This rock is slightly coarser and contains a higher percentage of andesite than the preceding. It is composed almost entirely of material of volcanic origin.

Stanton says that the line of division between Montana and "Laramie" falls within this ridge of dark-colored beds, and that the invertebrate fauna shows a transition from marine to brackish and fresh water conditions. His evidence is marine Cretaceous shells[1] found in the lower part of the Lennep sandstone and fresh water shells of the "Ceratops beds" fauna, together with bones and teeth of Triceratops and other dinosaurs, at the top of the formation. A few leaves collected from these beds in T. 6 N., R. 16 E., and T. 5 N., R. 17 E., are reported by Knowlton to be *Platanus* sp. ?, *Viburnum* sp., and a single specimen of *Halymenites major* Lesq., a marine plant commonly assigned to the Fox Hills. They are not sufficiently distinctive to determine the age of the beds. A collection of plants made by Stanton in 1903 in sec. 23, T. 6 N., R. 16 E., is listed by Knowlton as follows with the conclusion that it is a Livingston flora:

PLANTS FROM LENNEP FORMATION ON FISH CREEK.

Asplenium sp. (probably new),
Gingko adiantoides (Unger) Heer,
Sequoia (new species),
Sequoia sp. (cone),

[1] Stanton, T. W., "The Age and Stratigraphic Relations of the 'Ceratops Beds' of Wyoming and Montana," *Wash. Acad. Sci.*, Vol. XI., No. 3, 1909, p. 260.

Quercus ellisiana Lesq.,
Ficus auriculata Lesq.,
Ficus sp.,
Cinnamomum ellipticum Kn.,
Leguminosites Lesquereuxiana Kn.,
Dombeyopsis platanoides Lesq.,
Phyllites (not named).

A small collection of plants made by Knowlton and Calvert in these beds in August, 1909, 2 miles east of Widdicombe Brothers' ranch in T. 6 N., R. 16 E., is reported by Knowlton as Livingston flora. The collection consists of *Platanus* sp. and *Laurus* sp. According to Knowlton: "Both these are similar to unnamed forms from the basal portion of the Livingston beds of the Bozeman-Livingston area."

On the basis of this flora Knowlton asserts that the tuffaceous formation in which it occurs is Livingston. These beds directly underlie a considerable thickness of gray sandstone and shale on the head of Fish Creek concerning which there is a difference of opinion as to age. Since Knowlton refers the "Ceratops beds" of Hell Creek, Mont., and of Converse Co., Wyo., to the Fort Union, on the same grounds he calls these Fort Union or basal Tertiary. Stanton on the other hand maintains the late Cretaceous age of these beds. There is, however, no real difference of opinion as to the horizon represented here. Evidence of the age is given below. The following collections of leaves were made in sec. 15, T. 6 N., R. 15 E., in the Lance formation.

COLL. NO. 5515, 200 FEET BELOW TOP OF LANCE FORMATION.

Sapindus affinis Newb.
Sapindus grandifoliolus Ward.
Plantanus aceroides Gopp.
Platanus sp.?

COLL. NO. 5516, 400 FEET BELOW TOP OF LANCE FORMATION.

Platanus raynoldsii Newb.
Sapindus grandifoliolus? Ward.
Sapindus sp.

To both of these collections Knowlton ascribes Fort Union age without reservation. A collection of shells from the same section and occurring about 200 feet above the base of the Lance was determined by Stanton as follows:

COLL. NO. 6038. SHELLS FROM LANCE FORMATION.

Unio pyramidatoides Whitfield,
Unio verrucosiformis Whitfield,
Unio biesopoides Whitfield,
Unio holmesianus White?
Unio brachyopisthus White,
Unio stantoni White?
Unio sp.
Sphaerium sp.
Physa sp.
Limnaea? sp.
Goniobasis? sp.
Viviparus sp.

"The unios belong to the fauna that is so well developed in the 'Ceratops beds' of Hell Creek, Mont., and of Converse Co., Wyo."

As Knowlton considers the "Ceratops beds" to be basal Fort Union there is no disagreement here as to stratigraphic correlation.

Still farther east in sec. 7, T. 5 N., R. 17 E., in the bed of a small stream two miles southeast of the Strand ranch, Fisher, Woolsey, and Stone collected the following invertebrates:

COLL. NO. 4637. NEAR BASE OF LANCE FORMATION.

Unio brachyopisthus White.
Unio n. sp. (?) related to Unio retusoides Whitfield.
Unio n. sp. (?).
Campeloma? sp.
Limnaea? sp.

These shells are about 150 feet above the base of the Lance and are assigned by Stanton to the "Laramie" or "Ceratops beds." These collections are cited for their bearing on the position of the Lennep sandstone and the Lebo andesitic member and also on the question of the lower limits of the Fort Union.

No one questions the fact that the tuffaceous beds (Lennep sandstone), which here contain a flora assigned by Knowlton to

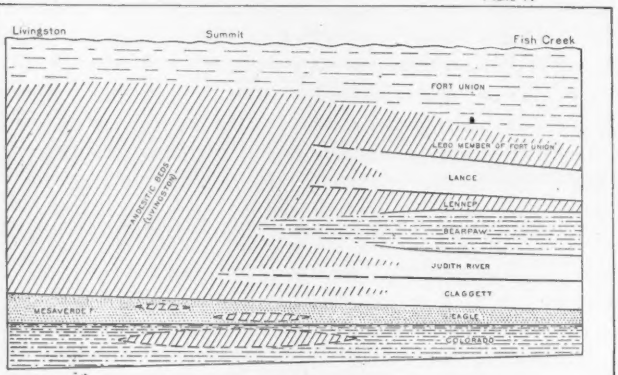
the Livingston, rest on Bearpaw shale. This fact is used by Knowlton as an argument for the existence of an unconformity beneath the Livingston formation on the assumption that the flora collected from the Lennep sandstone in T. 6 N., R. 16 E., is sufficient evidence for the exact correlation of that bed with the plant-bearing beds near the base of the Livingston in the type area where no formations comparable with the Bearpaw, Judith River, and Claggett are present beneath the strata carrying the Livingston flora. Knowlton explains the absence of these formations from the area around the town of Livingston by supposing if ever present there they were removed by erosion before the deposition of the Livingston andesitic material. The exact position of the supposed erosion surface in this section has been difficult to fix. Until recently it has been assumed to be at the base of the Livingston but the latest view, as expressed in a public discussion, places it lower, at some undetermined level within Weed's "Laramie" of the Livingston section because the flora of the upper part of the coal measures and of the Livingston have proven to be closely related.

The stratigraphic and other evidence presented in this paper is decidedly against the existence of such an erosion interval and tends strongly to the conclusion that the andesitic Livingston beds of the type area really include the time representatives of several formations that are distinctly developed northeast of the Crazy Mountains. In estimating the value of the plant evidence for correlating the Lennep sandstone of the northeastern area with the basal few hundred feet of the typical Livingston it should be remembered (1) that the flora of the overlying great mass of the Livingston formation is meager and very imperfectly known, and (2) that the flora of the Eagle, Claggett, Judith River and Bearpaw in the areas under discussion north and east of the Crazy Mountains are also practically unknown. It seems reasonable, therefore, to raise the question whether enough is known about the vertical and horizontal range of these species of plants to justify their use in such close correlation.

The field relations seem to point most conclusively to a dove-

tailing together of the tuffaceous Livingston deposits and the normal Upper Cretaceous and lower Tertiary formations as shown in the accompanying diagram (Fig. 75). For relations such as illustrated in the diagram there is abundant evidence in the field, but there is no stratigraphic evidence for an unconformity running from the Eagle up to the top of the Bearpaw. Nowhere so far as has been discovered throughout the sediments

Plate IV



Diagramatic cross-section in Livingston region illustrating interfingering of andesitic sediments with rocks not of volcanic origin.

involved in this discussion is there evidence to show that the deposition has not been normal and continuous. Certain it is that the Bearpaw shale grades up through a transitional zone into the tuffaceous beds at the base of the Lance, and that these tuffaceous beds grade into the fresh-water deposits above them.

The upper, dark-colored beds occurring between the Lance and massive sandstone of the Fort Union of the section in the Musselshell valley, and described[1] by Stone as the Livingston formation, will be called here the Lebo andesitic member of the Fort Union formation. The Lebo sediments are believed to be correlated stratigraphically with the upper part of the Livingston

[1] Stone, R. W., "Coal Near the Crazy Mountains, Montana," Bull. U. S. Geol. Survey, No. 341, 1909, pp. 80–82.

formation at the type locality, which is interesting in view of the fact that the lower part of the Livingston has been shown to be lower Montana.

West of Cottonwood Creek in T. 7 N., R. 10 E., the Lebo member is composed largely of gray, red, green, brown, and dark shale and sandstone, while in T. 6 N., R. 16 E., it is characterized as chocolate-colored, although the individual members are for the most part dark greenish and brown sandstones and shales with little or no light-colored beds. A decrease in thickness from nearly 2,200 feet in range 10 to 450 feet in range 16 is a noticeable feature and perhaps may be explained by the fact that the Lebo is composed to a considerable degree of volcanic material which came from the west, and therefore should be expected to thin eastward.

The following sections show the character of the Lebo member, on the northeast flank of the Crazy mountains:

SECTION OF LEBO ANDESITIC MEMBER IN T. 7 N., R. 10 E.

	Feet.
Shale, gray and green, and sandstone, dark, thin-bedded	100
Beds concealed	152
Shale baked with dike and sill	20
Sandstone, gray, thin-bedded and dark shale	167
Sill	5
Beds concealed	380
Sill	5
Beds concealed	315
Shale, dark, and red and green sandstone	320
Shales, red and green, red limy nodules, and tan and gray sandstone	720
	2,184

On the head of Lebo Creek in T. 6 N., R. 13 E., Fisher measured the following section:

SECTION OF LEBO ANDESITIC MEMBER ON LEBO CREEK, T. 6 N., R. 13 E.

	Feet.
Beds concealed, calcareous at top	740
Shale, dark, alternating with somber-colored sandstone; fossiliferous in lower part (Stanton No. 1,259)	1,340
	2,080

The shells found here are *Unio* sp. and *Viviparus retusus* M. & H.?, and suggest that these beds belong to the Fort Union formation.

Several miles farther east, on Fish Creek in sec. 15, T. 6 N., R. 15 E., Stanton and Silberling measured the following section[1] of these beds.

SECTION OF LEBO ANDESITIC MEMBER ON FISH CREEK, T. 6 N., R. 15 E.

	Feet.
Shale, with a few thin bands of sandstone	112
Sandstone, gray	5
Shale	18
Limestone, gray, weathering brown	3
Shale, greenish gray, with much soft sandstone of same color and brown ironstone concretions in lower third; a few thin bands of sandstone in upper part and several concretionary layers near top	700
Sandstone, brown, thinly cross-bedded, forming top of conspicuous broken ridge	32
Shale	200
Sandstone, greenish gray	15
Shale, greenish gray	249
	1,334

Where this section was measured the beds dip strongly to the south and have more of a chocolate color than noted farther west. At about the same place on Fish Creek, Calvert and Stone measured a section of the Lebo member by pacing across the steeply dipping beds and obtained a thickness of 904 feet.

In T. 6 N., R. 16 E., Stone measured a section from the lowest of the dark-colored beds up to the base of the massive sandstone of the Fort Union with the following result:

SECTION OF LEBO ANDESITIC MEMBER IN T. 6 N., R. 16 E.

	Feet.
Beds concealed	170
Sandstone, gray, weathers brown, with clay pebbles	5
Beds concealed; partly sandy shale	53
Sandstone, greenish-brown, thin-bedded	11

[1] Stanton, T. W., "The Age and Stratigraphic Relations of the 'Ceratops Beds' of Wyoming and Montana," *Proc. Wash. Acad. Sci.*, Vol. XI, p. 263.

Beds concealed; probably sandy shale	55
Sandstone, thin- and cross-bedded	15
Shale, dark gray to black	123
Sandstone, dark, massive	2
Shale, dark greenish	5
Sandstone, dark, massive	2
Sandstone, dark, weathers light gray	22
	463

The only fossils collected by Stone were from the base of the formation; a *Unio* related to *Unio gibbosoides* Whitfield and of no determinative value, and a *Sequoia nordenskioldi* Heer reported by Knowlton as from the base of the Fort Union.

A collection of leaves of determinative value was made in 1909 by Campbell, Stanton, and the writers in sec. 15, T. 6 N., R. 15 E., in the upper part of the Lebo member and close under the massive gray sandstone of the Fort Union. It contains six species and is pronounced by Knowlton to be a Fort Union flora. The list follows:

COLL. NO. 5,517.

Platanus Haydenii Newb.	*Sapindus grandifoliolus* Ward.
Populus cuneata Newb.	*Grewia obovata* Heer.
Populus amblyrhyncha Ward.	*Grewiopsis platanifolia* Ward.

In the upper beds of the Lebo member and in the overlying gray massive sandstone fresh water shells are common. They include *Viviparus,* several species of *Unio,* most of which appear to be undescribed, and *Campeloma multilineata,* which in some of its varieties ranges from the Laramie of the Denver Basin and the "Ceratops Beds" into the Fort Union.

Additional evidence of the age of the Lebo member on the northeast side of the Crazy Mountains is found on the east side of Bear Butte in sec. 4, T. 5 N., R. 16 E., 65 feet below the massive gray sandstone of the Fort Union. Here in a thin sandstone occurring in greenish shale Silberling made an important collection of mammals. On preliminary examination Gidley has recognized *Ptilodus montanus* Douglass, *P. gracilis* Gidley, *P. serratus?* (Marsh), *P. formosus?* (Marsh), *Mioclænus* sp.

nov., *Euprotogonia* sp. nov., *Didymictis* sp. nov., *Ectoconus?* sp. nov., *Deltatherium?* sp., *Psittacotherium* sp., *Chriacus* sp., *Pantolambda* sp., *Oxyclaenus* sp., *Tricentes?* sp., *Pentacodon?* sp., *Mixodectes?* sp. The two doubtfully determined species of *Ptilodus* described by Marsh occur in the "Ceratops beds" of Converse Co., Wyo. All the others are related to species in the Torrejon fauna of New Mexico, which was originally included in the Puerco.

In the massive gray Fort Union sandstones of the Fish Creek section *Clænodon ferox* (Cope) and *Pantolambda cavirictus?* Cope have been found. These mammals belong to the same general fauna as that enumerated above and are accompanied by an abundant Fort Union flora. These gray sandstones and the upper part of the Lebo member have also yielded the reptiles *Champsosaurus puercensis?* Cope and *Crocodilus* sp. Fragmentary mammal remains, among which Gidley has identified *Clænodon* sp. nov. and *Mioclænus?* sp., have been obtained from within about 50 feet of the base of the Lebo member on Fish Creek or just above the top of the Lance, and at practically the same horizon as a flora listed by Knowlton as Fort Union.

The evidence quoted above correlating the dark colored Lebo member with the Torrejon on the basis of mammal remains, and the determination of the flora as Fort Union shows that the Lebo member is basal Tertiary in age.

Many of the beds in the sections given above are tuffaceous in appearance and undoubtedly are largely composed of volcanic material. Unfortunately no specimens were collected in this area to determine this point. An examination of the matrix of the fossils, however, shows the tuffaceous character of the containing beds.

At a number of points in the Musselshell Valley northeast of the Crazy Mountains it was observed that some of the sandy beds in the Montana group have the appearance of tuffs. Certain beds in the Bearpaw shale and in the Judith River and Claggett formations so strongly suggested volcanic material that thin sections were cut from specimens of these rocks. These

have been examined by Calkins, Cross, Johannsen, and Stone, and the following were identified at tuffs:

C.M. 71. Tuff. From the Claggett formation in T. 6 N., R. 15 E., sec. 14. Consists chiefly of grains of plagioclase and altered lava, and has much ferritic oxide stain. All particles resemble andesitic debris. Appears like a flow tuff.

C.M. 74. Tuff. From near the top of the Claggett formation, 650 feet above the Eagle sandstone, in T. 6 N., R. 15 E., sec. 13. Consists of angular fragments of plagioclase and andesite, with a little hornblende; probably is tuffaceous.

C.M. 75. Tuff. From the top of the Claggett formation in T. 8 N., R. 12 E., sec. 29. Shows grains and pebbles of andesite in an andesitic groundmass. Probably is tuffaceous.

C.M. 76. Tuffaceous conglomerate. From near the base of the Judith River formation, in T. 6 N., R. 15 E., sec. 13. This rock is a conglomerate with subangular to rounded pebbles, chiefly of altered porphyritic andesite and one pebble of fine sandstone with angular grains of quartz. It may be an impure tuff.

C.M. 78. Tuff. From near the base of the Bearpaw, at the mouth of Lost Horse Creek, T. 7 N., R. 11 E., sec. 17. Consists of angular grains of feldspar, lava, augite, magnetite, and quartz, with considerable chlorite. It is a distinctly tuffaceous rock, like C.M. 75, but finer grained and darker.

C.M. 79. Tuffaceous conglomerate. From near the base of the Bearpaw shale, just below C.M. 78, at the mouth of Lost Horse Creek, T. 7 N., R. 11 E., sec. 17. Consists of rounded pebbles of augite-andesite or basalt, all of which are very similar. The rock probably is a water-rolled tuff.

RECAPITULATION.

In the foregoing chapters the endeavor has been to bring out several facts whose interrelations have not been discussed in detail. It has been shown that the coal measures of the Livingston section are of lower Montana age instead of Laramie, as previously supposed. The new interpretation is based on several lines of evidence. Fossils of Colorado age have been obtained from a number of localities a short distance stratigraphically below the coal-bearing sandstone. The sandstone itself carries an invertebrate fauna which, though scanty, correlates it with a fair degree of certainty with the lower Montana. Furthermore,

there is every indication of a conformable and transitional sequence from the Colorado into the coal measures, which certainly could not exist if the latter were of Laramie age.

That the coal measures of the Livingston type section are of lower Montana age is therefore considered as established, but the writers hesitate to state that they are the equivalent of the Eagle sandstone which is normally the lowest formation of the Montana group as developed in the state. In the Red Lodge-Nye area the coal-bearing sandstone corresponds in character and thickness to the Eagle, but in the vicinity of Livingston the coal measures are thicker than the Eagle as known elsewhere in the region. Two possible explanations may account for this condition: (1) the lower part of the coal measures may be typical Eagle, while the upper portion may be correlated with the Claggett formation which normally overlies the Eagle sandstone, or, (2) this formation in the vicinity of Livingston may be the northern extension of the Mesaverde formation of the Montana group as developed in Colorado and Wyoming. To the writers the latter assumption seems the more probable. The coal measures are about 300 feet thick west of the Crazy Mountains; at Livingston they are about 800 feet; while in the Electric coal field to the south they are nearly 1,000 feet thick. Moreover, the scanty fauna found in the coal-bearing sandstone at Electric occurs also in the Mesaverde formation in the Wind River Basin of Wyoming. It is well known that the Eagle sandstone and the Claggett formation pass into an undifferentiated mass when traced southward from the type localities and it is believed to be highly probable that such a transition is represented in the Livingston area. North of the Crazy Mountains the Eagle sandstone has a normal thickness and is overlain by distinguishable lithologic units, whereas to the south, especially near Yellowstone National Park, a thick and undifferentiated mass of coal-bearing sandstones overlies Colorado shale. Whether Eagle sandstone or Mesaverde however, the conclusion remains that the coal measures near Livingston, formerly considered Laramie, are lower Montana in age. That all the sediments above Colo-

rado shale in the Livingston type locality, up to the Fort Union at least, represent continuous deposition is borne out by all the stratigraphic evidence, hence the conclusion must be reached that in this sequence are the time representatives of the Eagle, Claggett, Judith River and Bearpaw formations as developed on the northeast flank of the Crazy Mountains.

Thus far the andesitic beds above the coal measures have yielded no marine fauna in the area south of the Crazy Mountains, which may be due either to the beds having been deposited in fresh water or under subaërial conditions, or if the beds are marine, that the influx of material was so rapid that the environment was unfavorable to marine life. That marine conditions prevailed west of the Crazy Mountains, however, at certain horizons is demonstrated by fossil collections north of Myersburg to which reference has been made on page 665.

East of the head of Potter Creek shale and sandstone appear intercalated in the andesitic beds and these carry a marine fauna characteristic of the Montana, and andesitic material occurs in diminishing quantity eastward. Northeast of the Crazy Mountains seven well defined lithologic units can be differentiated above the Eagle sandstone, only two of which are persistently of andesitic material as indicated in the accompanying plate of columnar sections. In other words, there is a "fingering out" of andesitic beds into the sequence of shale and sandstone normally found in the columnar section from Colorado to Fort Union inclusive. This is not a unique condition, however, as it is similar in many respects to the deposition of the Catskill formation in New York and Pennsylvania. In the accompanying figure the attempt is made to show this interfingering in a diagrammatic way.

From the standpoint of the stratigrapher and the invertebrate paleontologist therefore, the interpretations set forth in this paper as a solution of the "Livingston problem" are satisfactory, but in fairness it should be stated that the paleobotanist finds the evidence conflicting. The flora of the Livingston has been considered distinctly Tertiary rather than Cretaceous.

According to Knowlton the flora contains more than 75 species, more than half of which have an outside distribution. A majority are found in the Denver formation, yet a third occur also in the Fort Union, while only four species occur in the Montana as now recognized. If, contend the paleobotanists, the rocks overlying the coal measures in the Livingston section are of Montana age as claimed in this paper, why is the flora not comparable to that of the Judith River formation. To the writers this apparent dissimilarity merely indicates that the Judith River flora is imperfectly known. Of the recognized flora a large proportion of the species come from one collection, while the remainder occur in small lots disseminated in a zone extending from the Canadian border well into Wyoming, so that it does not seem improbable that the future will bring new light on the paleobotanical aspect of the Judith River and associated formations.

Attention might be called to the assertion of Knowlton and Peale that the flora of the "Laramie" of the Livingston section is closely allied to the flora of the overlying rocks. This being true, the idea that the "Laramie" and the Livingston are separated by "a period of intense vulcanism and of mountain growth" can no longer be entertained by the paleobotanist,—a new interpretation with which the stratigrapher is heartily in accord. This similarity of floras has been admitted only recently, for even as late as 1907 Knowlton asserted that the plants from the coal measures are distinctly Laramie in type. The idea of an unconformity *in* the coal measures of the Livingston section is now advanced by the paleobotanists. No one, however, has ever noted the slightest suggestion of such an unconformity in the field unless the statement of Eldridge that the main coal bed was laid down on an uneven floor may be taken to mean unconformity. Concerning this point Weed states that "the perfect stratigraphic continuity of the marine Cretaceous with the Laramie is everywhere apparent. No break occurs, and no evidences of unconformity have been observed, up to the top of the formation." This statement covers the field conditions

perfectly, and if a stratigraphic break occurs as suggested by the paleobotanist, it is certainly of an exceedingly obscure nature. Yet this unconformity, if it exists, must be of great magnitude, for it means the transgression by beds containing a Livingston flora across the Bearpaw, Judith River, Claggett and possibly down to the Eagle or its equivalent at Livingston—since the paleobotanist admits the possibility that the *lower* part of the coal measures may be of Montana age. This overlap must be most strongly pronounced in the vicinity of Potter Creek valley, since the entire Montana group is known to be present there as proved by Bearpaw fossils. There again, however, even where such an assumed unconformity should be most evident, its occurrence has never been suspected in the field.

In regard to the possibility of an unconformity *in* the coal measures at Livingston all the evidence argues against such a conclusion. Marine shells have been found (see p. 655) at the *top* of the coal measures. Plants are not confined to a zone closely associated with the upper coal, beneath which the paleobotanist would place an unconformity. On Boulder River, Calvert collected the following species, identified by Knowlton, and by him assigned to the "Laramie":

Protophyllocaldus polymorpha (Lesq.) Berry.
Protophyllocaldus lanceolatus? (Lesq.) Berry.
Sequoia reichenbachi (Gein.) Heer.
Anemia elongata (Newb.) Kn.
Leguminosites cassiodies Lesq.
Sequoia Langsdorfii?

On Boulder River the coal measures are 780 feet thick, and the leaves quoted above were obtained from two carbonaceous horizons 27 feet apart, *500 feet below the top of the formation, and over 300 feet below the upper coal zone.*

At Storrs plants assigned to the "Laramie" by Knowlton were obtained 150 feet *below* the upper coal. Even on the basis of plant evidence therefore the occurrence of an unconformity *within* the coal measures is not considered tenable by the writers.

Still another phase of the problem needs consideration and here no new evidence can be presented. In the Three Forks folio Peale makes the following statements relative to the Livingston:

> The largest (Livingston) area is probably that in the vicinity of Sphinx Mountain, where the Sphinx conglomerate rests unconformably upon it, (the Livingston). This area is about 15 to 20 square miles in extent, and the deposits are made up of a mass of volcanic materials indistinctly bedded, mostly andesitic in nature, and of a somber hue. This generally black mass rests unconformably upon the eroded surfaces of the previously deposited Cretaceous formations, contrasting strongly in color with the Laramie sandstones and the Dakota conglomerates, with both of which it is in contact. . . . The Livingston beds in the northwest corner of the district present a somewhat different aspect from those just described, being not so dark in color and showing more distinct evidences of bedding; they are also more nearly conformable to the underlying Laramie beds with which they are in contact.

These areas of Livingston rocks have not been examined by the writers, hence any judgment passed upon them at this juncture must necessarily be more or less hypothetical. The observations of Peale are important, however, and cannot be ignored. There is no question that the "Laramie" of Peale is the same as that of Weed in the Livingston section, and that the Livingston of the two areas is comparable in lithology and stratigraphic position. It will be noted that Peale states that the Livingston "in the northwester corner of the district is more nearly conformable on the Laramie," or, in other words, that the unconformity is one of overlap rather than of visible discordance in dip. It has been shown in this paper that andesitic material is no criterion of age, as in the Livingston area, adjoining the Three Forks quadrangle on the east, it occurs at various geologic horizons from Colorado to Fort Union. Hence if Peale mapped the Livingston on lithologic grounds, as he did in this northwest area, there might be the appearance of unconformity without one existing in reality.

The fact that a strongly marked erosional unconformity occurs at the base of andesitic beds in the vicinity of Sphinx Mountain does not render less logical the general claims advanced in this

paper. At the time the andesitic material was laid down near Livingston there must necessarily have been a nearby land area where the products of vulcanism were poured forth which supplied the Livingston sediments. Somewhere along the shore line then, unconformity might naturally result, and the indistinctly bedded character of the rocks constituting the Livingston at Sphinx Mountain is some evidence bearing on the contiguity of this hypothetical land mass. It seems to the writers, therefore, that even if there is no doubt of the reality of the unconformity in question in the Three Forks area, it does not invalidate the conclusions reached in this paper regarding the stratigraphic relations of the so-called Livingston formation elsewhere.

CONCLUSION.

A brief statement of the substance of this paper is as follows: A great thickness of sedimentary deposits occurring at Livingston, Mont., composed largely of tuffaceous material has been called the Livingston formation. It is described as lying unconformably on coal-bearing sandstone of Laramie age.

The evidence, both from stratigraphy and invertebrate paleontology submitted in these pages, shows that the coal-bearing sandstone is Eagle, or at least lower Montana in age. It is admitted by paleobotanists that the flora of the upper part of the coal-bearing beds is similar to the Livingston flora, the greater part of which comes from within 600 feet above the coal-bearing sandstone. The coal-bearing beds are transitional into the tuffaceous beds above. Therefore, the evidence of both stratigraphy and paleobotany indicates that the Livingston beds are conformable on the underlying coal-bearing beds.

The Livingston formation was originally described as a lithologic unit of tuffaceous material derived from volcanic activity, the material of which the beds are composed, and not the fossils, determining the extent of the formation. Beds of this character are most abundant in the Livingston region but they have been traced north and east around the Crazy Mountains where beds of similar lithology are found in all the formations from Colo-

rado to Fort Union, and where they feather out into and merge with fresh- and brackish-water and marine deposits.

Stratigraphic relations, marine invertebrates, and fossil leaves prove the Montana age of the lower part of the tuffaceous beds on the west side of the Crazy Mountains originally mapped by Weed as Livingston. Northeast of the mountains some of the tuffaceous beds are younger than Bearpaw and older than Lance, while the youngest of the andesitic deposits are Fort Union. From this evidence it is concluded that the lithologic unit of tuffaceous deposits originally described as the Livingston formation has no definite age, and no formational value except in the immediate vicinity of the type locality.

Even though the evidence here detailed may not be convincing to everyone, this paper is presented with the belief that its main conclusions will be verified if more detailed work on the stratigraphy and paleontology of the region is ever undertaken.

EDITORIAL[1]

THE CONSERVATION OF MINERAL RESOURCES.

The "conservation movement" which has been so widely discussed in the last few years is a more definite expression of what has been for a much longer period in the minds of many persons who have been well-informed regarding the mineral resources of this country; but from its use as the subject of muck-rakers' articles in more or less sensational magazines and as a political war-cry which will appeal to the ignorant albeit well-intentioned masses, it has become an object of grave distrust in the minds of not a few. Of the latter group the writer is one. As at present advocated and to a certain extent conducted, the movement comes dangerously near a dictatorial disregard of that clause in the Constitution that sets forth the inviolability of contracts, for it is difficult to see in what respect a contract in which the United States government is one party differs from that between individuals.

The Cunningham coal claims in the Controller Bay field of southeastern Alaska are the storm center of the conservatism movement to-day. Volumes of testimony have been taken in Washington and much impassioned oratory has been uttered by learned counsel. In the recent Congressional investigation emphatic statements were made on the stand by the advocates of conservation of what they proposed to prove, and it is not too much to say that those who have carefully read this testimony are still waiting for the revelation of any facts which will prove their statements. In the personalities of the case and in the diversion of attention to side issues such as whether or not the

[1] The signed editorials which it is designed to publish from time to time in these columns are expressions of individual views and do not represent the consensus of opinion of the editorial board.

attorney general or someone else, back-dated a document or not, the attention of the public is readily diverted from the main point of which as regards the coal claims the following is believed to be the truth.

The United States government encourages the discovery and location of mineral deposits and has done so for many years. The reward thus held out to a fortunate prospector has been one of the greatest influences in opening the western country and Alaska. With the support of a number of men of excellent financial standing chiefly in Washington and Idaho, and armed with powers of attorney from them, as, under the law was perfectly proper, Mr. Clarence Cunningham in 1903, penetrated this at the time, little known, very rough, inaccessible and unorganized region and staked out the coal claims in question. This was done under authority conferred by an Act of Congress, 1900, extending the general mining laws of the United States to Alaska.[1]

Later on in 1904, a new law was passed with regard to Alaska coal lands and soon thereafter Mr. Cunningham re-located all the claims, using new powers of attorney and observing the terms of the new law. The 33 locators of the claims then filed upon them, paid the required $10 per acre, about $52,800 in all, and received the usual certificates of purchase, but not the final patents. While it is unlawful for a prospector to locate coal properties if he has a prior understanding for conveyance after patent with a second party, so as, of course, to prevent dummy locations, yet once the ownership of a tract is secured there is no restriction upon subsequent sale or lease or development. Eighteen of the locators having their certificates of ownership then opened negotiations for their development, but the negotiations did not lead to any definite contracts. Somewhat over four years after the law mentioned above Congress passed, in May, 1908, further restrictions upon the locations of Alaskan coal lands, and subject to this law the Cunningham claimants were offered patents by Secretary Garfield. But, as their claims

[1] Reference to specific act.

were recorded and ownership obtained under an earlier law, they naturally refused to accede to post facto legislation. The whole matter has been still further complicated by the post facto activities of the Forestry Bureau which under Mr. Pinchot's administration has endeavored, in what seems to us a most arbitrary manner, to prevent the 33 locators from securing their patents. The whole matter moreover has been made such a political issue that it cannot fail to be unduly embarrassing to the President and the present Secretary of the Interior, who, if they do what seems to be their plain duty and issue the patents, are bound to suffer somewhat in general popularity. A full and very temperate statement of the whole matter is set forth by Mr. Horace V. Winchell in the *Engineering and Mining Journal* for April 23, 1910, pp. 860–863. While Mr. Winchell's statement will be taken unhesitatingly as final by all who know him, I may add that from other not less valuable sources, I have become familiar with this case and that both in matters of law and matters of fact I have become convinced that the claims are impregnable. Mr. Cunningham and his associates have been grievously wronged by autocratic and bureaucratic methods of agitation and procedure.

For those who do not know Mr. Winchell personally the case reduces to the credibility of two witnesses and the probability of the correctness of their testimony. Mr. Winchell's testimony is detailed and specific; that of Messrs. Garfield, Pinchot, and their former subordinates is vague, is based on suspicions rather than facts and is unsubstantiated. It seems incredible that any well-balanced mind could hesitate in reaching a decision as between the two.

This particular case brings up a general situation that has its serious side. The government holds out inducements. Prospectors avail themselves of the opportunity. They may go to great expense and effort, as in the Cunningham case, and may in the end be deprived of their proper reward by the autocratic action of a bureau chief. The law now prevailing may be faulty, but so long as it is the law, no generalities about the

"people's wealth" and no appeals to the collective cupidity of the masses ought rightly to prevent carrying out agreements.

But there are other equally weighty objections. In the recent so-called investigation of the present Secretary of the Interior. practically the sole tangible result was obtained by the prosecution because a confidential secretary was induced to violate one of the fundamental rules of ordinary loyalty to a chief, and committed an act such that if the practice were general, mutual confidence between men would be destroyed and society would be reduced to chaos. Happenings of this sort cannot fail to make the widely spread talk of the prominent conservationists about governmental righteousness and moral principles seem like the purest rot. It is little wonder that the conservation which they support becomes an object of grave distrust.

There are obvious objectionable features in our laws for the location of mineral claims. The exercise of powers of attorney, is one. Whole districts such as Nome have been tied up unendurably by their means. It would be better to require every locator to do his own locating in person. Powers of attorney are, however, at present quite proper under the law, and must in honesty be respected. Their abolition for future claimants to mineral rights would be one feasible method of promoting conservation.

The Apex law is firmly established for claims already recorded, but it has caused endless trouble, uncertainty and waste. Its repeal as regards new claims would be an eminently sensible way of promoting conservation. But while almost everyone freely admits its unwisdom, very little of the pent-up energy for conservation has been directed along the lines of this obvious reform.

In former years during the speculative and excited drilling for petroleum, extensive flows of natural gas were occasionally discovered. At the time no practicable use had been found for this priceless fuel, nor had devices been invented for its confinement and utilization. It was often burned as a huge torch, when not allowed to escape unconsumed into the air. This

wasteful procedure would now be reprehensible in the highest degree, and we find that nearly all the States where natural gas has been or might be struck have passed restrictive legislation. Every drill hole ought to be provided with some sort of valve whereby unrestricted escape whether of oil or gas could, under normal conditions, be prevented. Emissions might indeed be tapped under such great pressure that no valve would stand against them, but they would be rare and as a matter of every-day practice it would seem to be a fair requirement to have at the upper end of the casing some sort of a hinge or other valve which could either be closed by hand or which would be automatically closed by a sudden rush of oil or gas. It is also a fair proposition to restrict the number of wells upon a certain superficial area giving every owner of however small a tract one, as would be necessary under common law rights, but establishing a proper distance apart for those on larger tracts. Conditions could be reached which would prolong the life of a pool, and yet be fair to all concerned. Nevertheless, experimental wells are expensive, the business is largely a lottery, with fewer prizes than the uninformed realize and no legislation should be undertaken which kills the interest, or discourages the prospector from taking the chances which he has hitherto been accustomed to face.

In the matter of coal it is also fair to prevent waste. Thus some fifteen years ago in the Pocahontas coal region of Virginia the writer saw the operators compelled by the business conditions of mining to attack only the superb 8–11 ft. seam which yielded the famous coal of the district. Thirty or forty feet above was a seam 3 ft. or more in thickness which by itself at that time no one could profitably mine. The caving of the chambers in the thick seam bade fair to destroy the small one as a source of fuel certain to be needed before many years had elapsed. It seemed at the time as it does with increasing force now that the prevention by legislation of such destruction would be a perfectly reasonable step. An artificial barrier ought to be placed by law against the ruin of valuable resources and such

barrier ought to be one of the conditions to be met in mining, as inevitable and as real as the physical problems.

As time passes and improved methods of mining are more and more widespread, new plans of attacking seams may develop which will prevent loss in pillars and yet leave coal-mining a profitable business. Usually self-interest will of course prevent loss of coal but it is possible that the new Bureau of Mines may be able to suggest improvements in methods of attack or spread information about them which will be of real value. In metal mining in almost all cases there is little if any field for the interference of the Government. The companies themselves which are established upon profitable deposits are more anxious than any outsiders could possibly be to prevent waste or loss. The carefully trained and experienced technical men who are in charge and who have come to know the conditions, may almost without exception be trusted to manage their enterprises with the greatest possible economy. Governmental interference, exercised through the instrumentality of officers but imperfectly informed about conditions and at times over-zealous to make out a case for some remote official in Washington is repugnant in the highest degree to every one who can intelligently consider the question. Beyond safeguarding the lives of the miners so far as conditions admit; beyond collecting the proper levy of taxes and compelling a reasonably full and an honest periodic statement of operations and reserves, there is little ground for governmental restriction.

Regarding metalliferous deposits as well as coal there are in popular estimation widespread and very erroneous conceptions which are fostered by promoters of speculative enterprises and by writers of sensational articles in magazines. Mines are regarded as treasures hidden in a field, which one has only to dig up and enjoy, whereas, even a very limited experience soon shows that profitable ore-bodies are extremely rare, and that a hundred unsuccessful prospect holes are dug in order to find one or two that justify exploitation. Many an ore body which is profitable when worked on a large scale has been a cause of ruin

to men of smaller means. The chances of failure are so great that specially generous conditions for the locators of claims are necessary in order to have the prospector carry on his work at all.

The cheap magazines have spread many pages of wild statements, by men, of whom it is charitable to think, they knew no better. For instance, in an issue of *McClure's Magazine* the past winter there is an article upon Alaska coal fields, which credits them with a billion tons, worth a dollar a ton, and therefore worth a billion of dollars, all of which vast sum is being handed over to the unscrupulous rich! But it is of course elemental in coal enterprises to acquire enough to justify mining for a long period of years, say twenty-five, fifty or a hundred. Suppose an operator *will* realize the unusual profit of a dollar a ton upon coal mined twenty-five, fifty or a hundred years hence, or upon fractions of these periods, the real question is, what is the coal worth per ton today. Because an investor might put his money in a savings bank and without effort or appreciable risk on his own part have it double in twenty-five years, quadruple in fifty, and so on, we do not say that his one dollar is worth two, four, or eight today. No more is a ton of coal which may yield a dollar profit ten, twenty-five or fifty years hence worth a dollar today. That a purchaser will pay for coal in the ground more than a fraction of the profit he will realize for it, eliminating from the selling price per ton, when estimating purchase values, all that portion which belongs to mining expenses, amortization, interest on investment, and the like, seems too absurd to even combat. The billion dollars worth of coal soon reduces to a present value of twenty-five millions or some such sum and even this value can never be realized unless capitalists of large means make heavy outlays for railroads and shipping. The vast pity about a muckraker's article is that great numbers of the ignorant actually believe it while the few well-informed find cynicism almost the only philosophical resource.

J. F. KEMP.

DISCUSSION

This department has been established by the editors in order to afford to those interested in questions relating to economic geology an opportunity for informal discussion. Contributions are cordially invited either in the form of discussion of more formal papers appearing in earlier numbers or bearing upon matters not previously treated. Letters should be directed to the Editor, Sheffield Scientific School of Yale University, New Haven, Conn. The full name of the author should be attached to all communications.

SPECIAL PROBLEMS AND THEIR STUDY IN ECONOMIC GEOLOGY.

DISCUSSION OF EDITORIAL BY J. D. IRVING.

Sir: The editorial by Professor Irving in the last number of ECONOMIC GEOLOGY should be gratefully received for it contains criticism of the acceptable and beneficial kind—constructive criticism. At the outset I shall cheerfully admit that many of the points are well taken and that progress along the lines indicated—namely, the investigation of special problems, is not only desirable but necessary. Professor Irving refers to the fact that much of the economic work in metal deposits has been undertaken by the United States Geological Survey and it is from the standpoint of this organization that I would like to add a few words to the discussion.

First as to the size of the problems: Few people realize the enormous area over which the metal deposits of the United States are scattered, and the difficulty of covering the field at all adequately; there are many thousands of mines occurring under the most varying geological and climatic conditions; the prospecting activity is intense, and it requires no little work to keep informed on the new developments and discoveries. Old districts must be reëxamined in the light of the developments of ten or twenty years. Compared to the questions involved, the staff of the metalliferous section of the survey is certainly inadequate.

Second, as to methods of work: There are three ways open to the investigator, not two as Dr. Irving states. The first is the monographic method or the study of selected important mining districts in great detail. This he erroneously calls the descriptive geographic method. The second, to which scarcely any reference is made, is the true geographic method, and consists in comparative study of all of the mineral deposits in a given large area in order to ascertain their geological relationship and genesis. Frequently it brings excellent results because the true genetic relations are apt to be obscured in the largest deposits. The third is the method of the special problems, so ably explained by Dr. Irving, in which a single important problem—say that of secondary sulphide enrichment—is examined in deposits of a wide region.

The economic work of the Geological Survey began with examinations according to the first method, at Leadville by Emmons and at the Comstock by Becker; the second method was, however, not neglected in the early days, as indicated by Becker's monograph of the quicksilver deposits of the Pacific Coast, and the work in the gold-belt of the Sierra Nevada, a comprehensive plan which was never fully carried out. For a long time the monographic method prevailed, but during the last few years the emphasis is being laid on the geographic method. This is easily apparent by a careful study of the later publications of the Survey.

The Geological Survey is not primarily established for the study of abstract scientific problems, however much their elucidation may finally contribute to the solution of practical problems. A part of its duty is to examine and describe the mineral deposits of the United States for the benefit of the mining industry. Necessarily incidental to this a vast amount of purely scientific data is acquired and as far as possible it is the desire of the officers of the organization to collate and study these data so that important general laws regarding the genesis of deposits may be discovered. One would suppose this digestion and assorting of data might be a congenial task for the professors of univer-

sities but with few exceptions they have shown no marked enthusiasm for the undertaking.

The monographic method must be retained for its utility to the mines and the engineers has been clearly demonstrated. From the number of reports it might seem that "nearly all the larger districts of the west" have been examined, but a more careful scrutiny will show that many districts of first class importance, and hundreds of smaller mineral bearing areas have as yet received no attention. For the latter kind the monographic treatment is clearly out of the question; they must be included in the description of larger areas.

The Geological Survey must turn to the geographic method of describing ore deposits, for several reasons: (1) It is absolutely necessary to undertake a census of our metallic resources, to see where we stand, to estimate our probable productive capacity; to ascertain the extent of the mineral lands. (2) The Geological Survey must have information to furnish their innumerable correspondents and supply the legitimate needs of the engineers and local miners. The small districts may need attention even more than the large ones, whose companies are usually in a position to obtain the best geological advice without turning to the Federal government. (3) The safest way to obtain reliable conclusions as to the genesis of ore lies in a study of the geological relations of a large number of deposits over a wide area, for then the different classes of deposits and their age relations stand out in clear relief. Conclusions, drawn from the study of a single district, however large and important, has often proved misleading. (4) Our knowledge of the general geology of the United States, lamentably slight in many large western areas, will be greatly extended by this method.

The first comprehensive report of this kind is represented by the "Ore Deposits of New Mexico," recently issued.[1] The volume may perhaps be criticized as containing too much detail in some districts and probably the plan may be modified in other issues of this kind. It is proposed to issue similar comprehensive

[1] Professional Paper 68.

reports for the other States, as far as possible summarizing our information concerning them. Needless to say that this is not the work of a day or a year, and it will be necessary to publish many preliminary bulletins of smaller areas, in order not to withhold information.

The method of special problems will certainly form a part of the work of the metalliferous section as far as it can be followed by a small staff that is doing its best to handle tremendous problems. The members of the survey are pleased and gratified that the geologists and engineers of the country consider them equipped to approach these difficult questions. Sometimes they may feel that a little too much is expected from them. They note for instance plaintive inquiries from San Francisco friends in the mining press why some fundamental laws are not discovered, and requests that certain geologists may be detailed to unearth these missing principles. I do not believe, with Dr. Irving, that such discoveries are a matter of chance or of opportune requests for papers from scientific or engineering societies. They will come in due time but it is not advisable to foster them too violently by hothouse methods. They must rest on the solid foundation of exact observations, and numerous observations otherwise they are not likely to stand. Compilations of existing literature may be valuable, but only if they are made by the men best qualified to investigate the particular problem involved. Such special investigations are not a matter of short time; to take an example, it would undoubtedly be of great benefit to any one writing on sulphide enrichment to travel and see a great number of deposits. But here again it is a question whether such necessarily superficial examinations would really solve the problem. Take the Comstock lode, for instance. An investigation of its enriched ores is urgently needed, but does any one imagine that this can be done during a visit of a few days? Here again we come back to the already emphasized conclusion that to be of value for generalizations, observations must be accurate and plentiful. If I am not mistaken, the elucidation of the Comstock problem would require about a year of the time of a good mining geologist.

The field of special problems is a large one and we should be grateful to Dr. Irving for pointing out a number of them, even if we may regret that he doubts (in his second question) such a well established fact that metallic sulphides may be original constituents of igneous or sedimentary rocks.

That our literature is becoming bulky is true, but is it not because our metallic production is likewise swelling to unprecedented proportions? An effort will be made to reduce the details in the geological reports to a minimum amount. An omission of detailed descriptions would probably, however, bring forth a spirited remonstrance from the mine owners and engineers who take a more directly practical viewpoint.

It can hardly be admitted, however, that the sufferings of the searcher after truth are as pathetic as painted, for the important results are always given in the general part of the reports where they can be found with comparatively slight labor, with the help of excellent lists of contents and index. What is more difficult is really to find one's way among the volumes of the scientific journals when hunting for information bearing upon special points.

The geologists of the Federal Survey gladly accept the criticisms and will surely endeavor to improve and extend their work. The requirements upon them are—and must be—many-sided, and they plead guilty to falling short of expectation at times, in their work. But they are not willing to admit that they do not see their opportunities, nor that they work without definite plan and aim. With the vast field before them they must ask for time to cover it—and to do it well.

WALDEMAR LINDGREN.

Sir: I have read with great interest your editorial on the importance of studying special problems in economic geology, and of making such studies the themes of published bulletins by geological surveys. The titles of proposed problem investigations which you suggest are all of them academic. Your suggestions would be taken as a matter of course if the suggested

studies were a list submitted to the Carnegie Institution of Washington. They become polemical, if not openly belligerent when carried into the field of federal or state surveys. At the same time all geologists who have a real love of scientific progress sympathize with the underlying ideas of your criticism of existing geological surveys and the war waged is the ancient one between those whom Aristotle characterized as "always hunting after the profitable" and those seeking "that which tends to virtue and is really excellent." This struggle is going on wherever the self-seeker antagonizes the altruist, or where the ignorant encounters the learned, or the materialist crosses the path of the seeker of ideals. It is fair to the geological surveys, however, to conclude that their scientific staffs are actuated by the love of pure science quite as much as is any academic body. Can we not, therefore, find some solution for the conflict with legislators which you cite, through the mechanism of publication, without any drastic change of policy?

It seems to the writer that the topical discussion of scientific themes ought to be published by geological surveys, or any other publishing agent, in volumes which are avowedly of a different class from regional reports. The geographic side of geological work is all-important, and every young geologist should spend many years in mapping which is more or less mechanical. The writing and publishing of texts to accompany geological maps might in these days be done by a force of properly trained clerks, and if the texts accompanying atlas sheets were so published, and were confined to statements of fact, there would be much less diversity among them than is the case at present. When you decry "mechanical mappers and soulless statisticians" you seem to me unjust. Mechanical maps and soulless statistics are absolutely essential for all our geological work, and our greatest men of true genius have spent many years of their lives compiling both. The compilation of this material might, in many cases, have been done by office workers of lower grade, so far as mere arrangement of facts is concerned, but never the field work. The tradition exists and has taken deep root in the geological mind

that every field surveyor must write his own report. The reason for this view is the all-prevalent custom of making reports which accompany maps a hodge-podge of fact and theory. I believe, after years of experience in teaching students geological mapping, that it would be possible without great difficulty for a geological survey to so regulate the mechanism of its field note-books, specimen collections, field maps and laboratory reports that all records of fact in their relation to atlas and structure-sections might be compiled and arranged in texts and tabulations by a force of clerks. Geology has now become sufficiently systematic to be treated like topography in this respect. So far as art and judgment need come into the records of a geologist's field mapping, these may all appear in his rough color sheets and in the form of his statements of fact.

If such an arrangement as this could be made, the field man would then be free to treat the problems which most interested him in academic fashion. With the duplicates of his rough maps and notes he could devote himself wholly to true scientific work. The younger men would necessarily spend some years in combined field and clerical work, and on the other hand, the men advanced in years and attainments would, with the assistance of their juniors, be relieved even in the field of cartographic routine. The vital cleavage line should rest with the publications. If it were decided, for instance, to call all topical writings monographs, then let the authors of such works have an absolutely free hand in their authorship. Let it be understood that no bureau or society assumes any responsibility for the style, substance, opinions or theoretical conclusions written by monograph authors. Responsibility begins and ends in the choice of the man. On the other hand, the bureau or society in question should assume all responsibility for the non-monographic routine publications with their maps and texts, and see that the facts recorded are as nearly true as possible.

It may be urged that this cleavage is nothing new and that the monograph has always been set apart from the bulletin or atlas text. There is such a distinction vaguely conceived of in

the minds of most of us, but it is not enforced in practice. The monographs and professional papers—the last being monographic in character—of the United States Geological Survey are many of them geographical or regional reports, with theoretical conclusions indiscriminately mixed with collections of facts. Moreover, this federal organization sometimes attempts to censor matters of theory and opinion as well as accuracy of fact. The result has been a singular divorce between the institutions of learning and the Government Bureau which has grown up in the last ten years. This has been occasioned chiefly by delay and inadequate accomplishment of routine cartographic work by college men. The geological survey was forced, with a view to the efficiency of its service, to put this work into the hands of its permanent staff, and the college men frequently became aggrieved and in some cases withdrew from government employ with loud published outcries of chagrin. The Washington Bureau was in the right in most of these cases, and the college men were necessarily quite unable to serve two masters during the academic year with the same fidelity that they served one in field work during the summer. Many of these college men, however, could they have turned in their records of fact to be compiled by others, would have been glad to publish in government monographs their theoretical conclusions on selected topics. They would not, however, consent to do this if they knew that even the text of their topical treatment of science was to be censored unmercifully by an officialistic clique of topical chieftains, presuming, under the ægis of a bureaucratic oligarchy, to dominate geological thought in America. If, on the other hand, they felt assured after being invited to write a monograph by the government bureau that they would have the same freedom of expression, arrangement, orthography, illustration, and opinion as in the publications of their own academic institutions, the college men would welcome the honor so conferred upon them, and for very small recompense provide valuable and eclectic discussions of many important topics. It is just these discussions, as I understand it, which your editorial complains are now wanting in America.

The government bureau would be wholly justified in a censorship by topics of all that half of its work which concerned cartographic detail and statements of fact. It would profit by the friendly criticism, controversy and open discussion of theory which would be sure to develop in its uncensored monographic publications, where individual personality, literary style and sound learning would be given free sway, and each man whom the Bureau thought fit to accept as an author, would feel no restraint in voicing the best results of his mature thinking.

T. A. JAGGAR, JR.

November 1, 1910.

Sir: I have read with great pleasure the editorial in No. 7 of ECONOMIC GEOLOGY. It strikes a right note and should appeal to every mining engineer and mining geologist. There is no question of the correctness in the statement regarding the availability or rather I should say the unavailability of classified information upon given lines of research or investigation. Practically every report of the geological survey contains papers or monographs relating to the study of some special problem, brought out during the investigation of the particular area under consideration, but seldom correlated to similar problems previously studied and reported on in other areas.

It certainly would be of great aid to every mining engineer and would greatly enhance the value of the geological survey's publications if they would issue from time to time a bulletin specially devoted to one or more of the great problems of practical geology, being a compilation of preceding desultory reports on such problems contained, but possibly buried up, in their areal reports. To this matter should be added all information possible relating to the same problems, which may have been studied and discussed by other observers than those attached to the survey. It might be a question whether the survey as a present constituted could extend its usefulness along these lines, but there is no question as to the desirability of their doing so if possible.

I seriously question however the practicability of your sugges-

tion that our federal survey might assign the special study of these problems exclusively to any one investigator as that might tend to cripple and emasculate the work of every other investigator now in the field.

It appears to me also that the solution of any given geological problem is more apt to be really correct when the data on which it is solved represents the coinciding and cumulative views of a large number of independent trained observers, rather than emanating from one investigator who would be more likely, even though unintentionally, to gradually formulate a given theory, and strain every point to interpret the observed phenomena along lines favorable to that theory.

The one thing certain however is, that a compilation of all observations along the lines of the several questions you have mentioned would be of inestimable aid, to the field engineer in all future examinations, and it is to be hoped that some such compilation may shortly be published, either by the federal survey, or some other body of men engaged in original research.

E. GYBBON SPILSBURY.

Sir: I read your editorial and at once began to write a letter to you. But my expressions became more forcible than becomes a man who has retired from his work and who is seeking to live in reasonable peace with all mankind.

Your editorial strikes at an evil which is increasing with threatening speed. I have been engaged for years in preparation of a monograph, that ought to have been completed years ago, but I am still in the preliminary step, plodding wearily through many thousands of pages, filled with unimportant notes, with no grouping of facts, no presentation of relations between the petty area described and the great regions beyond. The authors, too often, seem to have regarded their districts as though they were individual planets wandering alone through space.

I have no desire to criticise the observers—the fault is in the system. As a rule the individual areas have always been too

small and the workers have been independent. As an illustration: on the Pennsylvania Survey, the Platt brothers were at the east of my area, afterwards at northeast; White was north. But we were never brought together for conference. Each went on his own way and when we came together we did not always agree in classification, though our work agreed closely. Different names were assigned to the same things by the observers in the different fields of work. The conditions were not so bad in the coal areas as in other portions, for happily the districts assigned proved to be reasonably good geological provinces.

It would be a blessing if some men could be assigned to the work of correlating observations so that observers may be able, in reporting their work, to be systematic. No one should censure the geologists because they give merely field notes: no other course is available. But if the salient features of a great area were known, if the principal divisions of deposits were reasonably well-defined, the workers throughout the area could be required to divide their reports into systematic and descriptive portions.

J. J. STEVENSON.

Sir: In his editorial on the respective merits of areal work and problem work in economic geology, Dr. Irving touches a matter of vital importance. While he limits his discussion to economic matters, it is scarcely less pertinent to work regarded as purely scientific. The attitude taken by Dr. Irving is so judicial in its recognition of the imperative value of each line of effort that it is almost beyond debate, however much a further discussion of the subject may help to emphasize special aspects. It will scarcely be denied that it is indispensable to the best outcome in the end that the foundations of the science be laid firmly in concrete facts and in basal principles equally; in local details and in wide summations alike. The practical problem is to compass both these to the highest measure permissible with such talent as is available or producible, and with such finances as are pro-

curable. Dr. Irving strikes a vital note when he points out the duty of the profession to educate the public and the public's legislative representatives to right ideas and to wise action, for the root of the matter lies largely here. It is the duty of the engineer to direct the current, not merely to float on it.

The question of a revised distribution of effort takes special shape according to the class of workers or of working organizations involved. Three such classes embrace the larger number of working geologists: the official surveys, the universities and the professional experts.

The official surveys of this country, state and national, seem to me to offer in their constitutional bases lines of diversity of effort that are clear and fundamental and that precisely fit the case. These lines are at the same time lines that define harmonious coöperation; lines whose adoption makes for mutual development. These lines are identical with the original distribution of governmental functions between the States and the general government provided in the federal constitution. That which is measurably local in government is the function of the several States; that which is common to all and is fundamental to the well-being of the whole is the function of the general government. A precisely similar division seems to me to hold respecting the scientific work of these coöperative governments. The general and the fundamental work is the peculiar function of the national organization. This is the only organization that is officially authorized to take up work in all the States. It is hence the only governmental agency that is properly commissioned to follow up a special problem throughout the national domain. The work urged by Dr. Irving is precisely the kind of work that the national survey is free to do and can do with the most complete appropriateness.

The local descriptive work is obviously the appropriate work of the local governments. Such work as has its chief relations to individual deposits, as distinguished from classes of deposits, also falls naturally to the local organizations and to local methods. Since the benefits of such work are largely local also, the members

of local organizations or institutions are best situated to do the work and to reap the personal rewards. They are members of the special community that is chiefly benefited.

All this holds true without admitting any hard and fast lines between the functions of the States and of the nation respectively. It is simply an appropriate cleavage plane for a distribution of labor which is greater than both together can adequately perform. It furnishes a good working basis for healthy coöperation. There must, in the nature of the case, be a free interdigitation of functions and a generous interchange of comities, if the best results are to be achieved by either party.

That the general government may properly do much in the line of local mapping finds a sufficient argument in its ownership of lands and in its obligations to conserve the resources that are important to the nation as a whole. On similar grounds also rests its obligation to assemble data into the unified form of maps of the whole country for the benefit of the whole people, whether these maps be topographic, geologic, biologic, economic or otherwise. On similar grounds also rests its duty to assemble and organize into a unified and systematic body of truth all that relates to the nation's resources, natural or scientific, and to develop therefrom and give to the nation and to the world such underlying principles and generalizations as the data warrant.

Among the universities there are somewhat analogous constitutional features that influence the distribution of effort. But these are somewhat more subtle and enforce less specific obligations. Besides, in the universities choice of effort is more individual and freer. The state universities are naturally associated with the state surveys in function and tendency. They are interested in the development of state resources. At the same time university workers feel the influence of the atmosphere common to all universities. The scholastic impulse prompts to the assembling of data, and to its organization into a systematic body of truth. To typical workers in the independent universities this is naturally the foremost impulse. In neither class of universities, however, have facilities yet become adequate for the

freest and most effective work but facilities are increasing rapidly. In the absence of institutional means the university staffs have very largely sought work on other than their own most appropriate lines, work on official surveys or on private commercial enterprises. In both of these they have been led largely into local work and this has intensified the unbalanced tendency which Dr. Irving deprecates. Given an appropriate distribution of effort on the part of the general government, given also its cooperative influence in the lines of the broader and more general work, the universities should more largely fall into their proper place in developing the science and in producing the appropriate kinds of workers for both phases of professional development.

Professional experts are naturally tempted by practical considerations into economic specialization and to areal concentration. Ideally they are perhaps freer than either of the preceding classes. Clearly they may specialize on subjects as well as on local deposits, may specialize on modes of origin, as well as areal distribution; on qualitative as well as quantitative occurrences. There is little ground to doubt the soundness of the proposition that in the long run the broader and deeper the studies and the more complete the mastery of principles, the higher the rewards.

The individual choices made by this third class of workers are quite sure to follow in some measure the lead of the national survey and of the universities. If these latter give a due measure of their influence to the development of the broader and deeper aspects of our science which Dr. Irving justly regards as most in need of cultivation, the desired distribution of effort will be measurably realized among all classes of workers.

T. C. CHAMBERLIN.

Sir: Your editorial upon the above subject in the October–November number of ECONOMIC GEOLOGY is one with which I am in complete accord, barring a few general statements of fact to which exception might be taken. I believe that you have correctly diagnosed present needs in the study of ore deposits. The descriptive or geographic method of approach has been used not

too generally, but too exclusively. There have been many excellent reasons for this and among them, certain difficulties that administrative officers have faced may properly be urged. A geological survey without funds is not a very useful institution and practically all who have had the duty of securing public money for survey work in America have found that appeals for support for studies of areas rather than subjects met with the readier response. Our whole system of political government has been based upon geographic distribution of powers and duties, and in the past an American's most important relations were geographic. It is only in recent years that a man has been expected to be more loyal to his business, his union, or his profession, than to his State, and a wise administrator works with, rather than counter to the spirit of his times. Aside from this, it is easy to convince most men that a survey requires systematic study of the whole of an area and so to secure time and money for continuous, careful work. Call for help for studying a specific problem of importance, and it will usually be obtained, but at the expense of a wholly new campaign when the next problem is to be undertaken. Whichever may have been the wiser route, there can be no question that the former was the easier, and with the history of American geological surveys in mind, it is not surprising that directors have taken every possible advantage of position when called on to face appropriation committees. I would not defend the report "on the farm of John Smith" that "may help to enhance the popularity of local politicians" but I would insist that the help of many politicians is necessary in order that geological surveys be made.

A director, however, should do more than keep the machine going. His should be the task of studying the field and planning future, as well as present, steps. Presumably the captain of an ocean liner is on the bridge that he may see ahead a bit; and it is well if he leave to the engineer the oiling of the machinery. Possibly our directors have been too anxious to handle part of the cargo themselves or too concerned with friction in the mechanism. Public opinion, however, among geologists and engineers has

been rather insistent that a director be not too ready to discard the khaki of the field for the general's uniform. The men in charge have done what they could rather than as they would. The state surveys, I feel sure, have made their full relative contribution to subject as well as area work. Dr. G. H. Cook's report on the "Clays of New Jersey" is much more than a list of localities, being, indeed, a highly useful work today. The series of reports issued by the Arkansas Geological Survey are notable contributions to science, and are special reports. Dr. R. A. F. Penrose, Jr., in preparing his volume on manganese, made exactly that broad study of a single subject that you ask. Dr. J. C. Branner showed his far-sightedness in his plans for the Arkansas Survey, but I would respectfully call attention to the fact that both the plans and the work were ahead of the time in Arkansas and that excellent organization had but a short life. Whether any other American State would have gone farther then is beside the question, since they did not do so, though many of them, then and later, supported areal geological work. The influence of Dr. Branner's example has been large. In Missouri Mr. Arthur Winslow made a broad special study of the lead and zinc deposits and nearly twenty years ago formulated conclusions which, somewhat modified it is true, form now an important part in our theory of ore genesis. Many other instances might be cited but the point is of minor import.

The real basis for so much descriptive work in the past was that it answered the need of the time. It was not only needed then but was also essential to the next step. Many fossils had to be described before study of migration of faunas became possible, and many ore deposits had to be studied in detail before the facts were at hand that would permit any trustworthy generalizations. The same has been true in the development of other sciences. Long years of work in systematic botany preceded studies of ecology and made possible the present brilliant work in breeding plants to order—creating new species at will. In zoology, chemistry, physics, astronomy, the history has been the same. Our

younger science has yet to step out into the creative, or rather here the predictive, stage. Geologists have been properly, albeit too exclusively, concerned with the past. Accurate reconstruction of a pterodactyl is a fascinating and useful task, but accurate forecasting of earthquakes and volcanic eruptions would be at least equally worthy and interesting. We have talked bravely enough about the pre-Cambrian, but how about the tomorrow? The Leadville Monograph has been much read and deservedly praised, but imagine the reception that would be accorded an equally authoritative discussion of where another Cripple Creek or Goldfield might be found. I would not belittle the useful work that has been done, but I would join in urging better work in the future.

The problems you have listed, and others that may be added, are all of intense practical as well as scientific interest. They intimately concern the future development of ore deposits as well as of the knowledge of ore genesis. They are worthy of most systematic and painstaking study. They are, however, too big for the resources of any single institution, even the United States Geological Survey. In attempting their solution, geologists and mining engineers would do well to profit by the experience of the civil engineers and the chemists. When concrete suddenly came into use there was an almost complete absence of the scientific data necessary for its safe and economical use in buildings. As a result there were numerous and disastrous failures. The engineers, facing the dilemma, organized a joint committee for research. This committee formulated the problems and parcelled out the work to various existing institutions, and, where there was a gap, secured from Congress the funds with which the technological division of the U. S. Geological Survey went to work on structural material. Schools, manufacturers, practicing engineers, state and government bureaus, all coöperated and are still coöperating; with the result that individual researches large and small have been made to fit together. Rapidly the problems of the engineers are being solved. In the same way the chemists,

being called upon to study problems relating to smelter fume and the damage that it does, have formed, with the assistance of the American Chemical Society, a central committee to bring together existing data and promote additional research.

Students of ore deposits in America have the aid of many existing institutions, but what is needed is some common plan of studies and some central stimulating agency. Would it not be well to have a committee including representatives of the U. S. Geological Survey, the Association of State Geologists, the Geophysical Laboratory, the Geological Society of America, the American Institute of Mining Engineers, the Mining and Metallurgical Society, and the mining schools? It would be still better if the Canadian Mining Institute and other institutions north of the line were asked to join. The general committee could meet perhaps once a year but in the main would need to work through subcommittees since numbers, while helpful in discussion are harmful when it comes to action. The expense of such a joint committee need not be large and would not be prohibitive. No new channel of publication is needed and each of the institutions suggested already has means for carrying out whatever piece of research might be suggested to it. What is needed is correlation of effort. It is not important whether the best general paper on ore deposits be published as a U. S. Geological Survey bulletin, as a separate from the *Transactions of the American Institute,* or in ECONOMIC GEOLOGY, provided it be published. The essential thing is that a few men be working on these broad problems and that they receive the aid from the remainder of us who must necessarily make such work incidental to other duties, that will be most helpful.

As a definite practical proposal I venture to suggest that the Geological Society of America at its meeting this month be asked to appoint a small committee to bring the matter before other societies and institutions and to secure their coöperation. The Association of State Geologists usually meets at the same time and place as the Geological Society, and meetings of the American

Institute, the Canadian Institute, and the Mining and Metallurgical Society will be held within the sixty days following. By calling their attention to the matter it should be possible to quickly determine whether the plan has in it any promise of usefulness.

H. FOSTER BAIN.

SAN FRANCISCO, CALIFORNIA,
December 5, 1910.

REVIEWS

Soil Fertility and Permanent Agriculture. By CYRIL G. HOPKINS. Ginn & Co. Pp. xiii + 653. Figs. 14.

The more patent applications of geology are of such evident practical value to mankind that there is little danger of failure to recognize their importance. Deposits of the precious and useful metals and their ores, workable quarries of rock, beds of gypsum and even of sand gravel and clay are of such obvious usefulness and afford such an inviting field for exploitation that we are liable to overlook the most important of all the geological products, namely, the soil.

Professor Cyril G. Hopkins, of the Agricultural College of the University of Illinois, is performing a great service in riveting the attention of thoughtful men upon the problem of permanent utility of our soils, and his recent book is a notable contribution to this work. His point of view is that which might be taken by the officers of a corporation conducting a business that is the nature of things should go on indefinitely. The great bulk of the farming of this country considers only the crop of the current year or at best those of a quarter century, remote posterity being given no thought. Yet with all of our efforts in the establishment of the doctrine of conservation, the most vital point of all, the conservation of the soil, is left to the little-appreciated care of comparatively few men who too often are regarded as mere theorists.

Doctor Hopkins's view-point is that which contemplates a continuous use of the soils of the entire earth through centuries to come. He addresses his argument to the student and to the busy farmer as well, and both will find his book to richly repay careful study. For the former the author gives in Part I., "Science and Soil," a systematic presentation of foundation facts and principles of chemistry, the composition of many compounds related to agriculture, the chemistry of plants and of the earth's crust, the formation, classification and composition of soils, soil surveys, soil analysis, crop requirements and sources of plant food. The farmer is advised to skip all this, and, after making some twenty paragraphs of highly condensed matter "a part of his ever ready knowledge," to go at once to Part II., "Systems of Permanent Agriculture." While assimilation of the twenty paragraphs without the illumination afforded

by well-directed reading and study bearing upon them may well be doubted, Part II. is of such a character that intelligent men can understand and use it with no serious difficulty.

Doctor Hopkins erects his superstructure of argument and advice upon the fundamental fact that limestone, phosphorus and organic matter are the only constituents that must be supplied to most of the normal soils of the United States in order to maintain their fertility indefinitely. The limestone to prevent acidity, the phosphorus for its plant-food value and the organic matter as a source of nitrogen and as a means of rendering mineral constituents of the soil available. He combats in uncompromising fashion the attitude of those who seek to estabish the view that all soils possess all of the mineral constituents in sufficient quantity for permanent agriculture. While toxic substances of various kinds undoubtedly have an important bearing upon the productivity of soils, as long as the law of conservation of matter obtains it will be necessary to give attention to the protection and restoration of the essential mineral constituents of plants occurring in minimum quantities in soils.

About one third of the book is occupied by Part III., which presents the results of soil investigations by culture experiments. In this the observations at Rothamsted and at the experiment stations of Pennsylvania, Ohio, Illinois, Minnesota, the Southern States and Canada receive ample attention and largely by direct quotation from their publications.

Part IV. includes thirteen chapters on "Various Fertility Factors." These are in a measure independent of each other, each contributing to the general view. An appendix contains tables and other material designed for reference.

The book as a whole represents an enormous amount of labor and is easily the most compendious presentation of the data of soil fertility that we have. It is written with the vision of a prophet and seer, considering the distant future as well as the present, the effects of geologic processes in amassing our heritage in the soil, and the dire results that follow the careless or ignorant exploitations of man. It should be in the library of every student of agriculture or economics.

J. T. WILLARD.

Outlines of Geologic History with Especial Reference to North America. By BAILEY WILLIS and ROLLIN D. SALISBURY. University of Chicago Press. $1.50 net, $1.66 postpaid.

This is a valuable republication under the editorship of Professor Salisbury of a series of notable papers presented by seventeen different geologists at the Baltimore meeting of Section E of the American Asso-

ciation for the Advancement of Science in December, 1908, and constituting a symposium on geologic correlation. The plan, which this volume shows to have been successfully carried out, was conceived by Mr. Willis who also contributed largely to its realization. The reviewer regrets that the restricted scope of a journal devoted to economic geology necessarily prescribes briefer notice than is really merited by a work so wide in geologic range.

F. L. RANSOME.

Geologische Charakterbilder. Edited by Dr. H. STILLE. No. 1, Eisberge and Inlandeis in der Antarktis. By E. PHILIPPI. Berlin, 1910. 3 M. 60 Pfg.

This is the first of a series of reproductions of excellent photographs illustrating characteristic geologic agencies and their results. In the present number are six views depicting the forms assumed by icebergs and land ice in the Antarctic, each being accompanied by a page of descriptive text.

F. L. RANSOME.

ERRATUM.

Figure 59, accompanying Mr. Clapp's paper on "A Proposed Classification of Petroleum and Natural Gas Fields" was placed upside down. In order to clearly understand the meaning of this cut, it should be turned over.

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